DEPARTMENT OF SURFACE ENGINEERING

F-4

The main activity of our department is the tailoring of surface properties of materials using thermodynamically non-equilibrium gas plasma. The basic principle of processing materials with gas plasma is the following: first, we select a suitable gas or gas mixture, and then we create a discharge in the selected gas so that a suitable density of free electrons is reached. Gas molecules, which are close to the ground state under normal conditions and room temperature, are excited to different states with high potential and/or kinetic energy during inelastic collisions with free electrons. Molecules in such energy states then react with the surfaces of the materials. Interactions of molecules in energy states can lead to functionalization, etching or deposition of coatings.

Head:
Prof. Alenka Vesel

When functionalizing the surface of a material, we always change only the composition of the surface. The best effects are achieved by choosing neutral molecules or molecular radicals, including neutral atoms in the electronic ground state. Neutral gas particles are not affected by an electric field, so they have negligible kinetic energy. The treatment of the surface of materials with neutral plasma particles leads to a change in the surface chemistry due to an irreversible interaction. The surface properties of the materials treated with neutral plasma particles are often far from a thermodynamically stable state, which is why the materials treated in this way tend to age – the surface energy spontaneously decreases until a stable state is reached. Plasma-functionalized materials are suitable for further processing, for example, the application of a coating, which can be an adhesive, a print, a thin metal coating, or some organic coating with characteristic properties (antibacterial, antioxidant, etc.).

The etching of materials can be the result of intense chemical reactions or the exposure of surfaces to energetic, positively charged ions from the gas plasma. In the first case, the method is chemical plasma etching, and in the second, it is sputtering. Sometimes a combination of both surface interactions is used, and the technique is called reactive ion etching. The etching of workpieces with plasma particles with high potential and/or kinetic energy is often laterally inhomogeneous, which can lead to nanostructuring of the workpiece surface. Nanostructured materials always exhibit exceptional surface properties. By properly choosing the type of neutral plasma particles for processing the materials that we previously nanostructured, we can achieve an extremely wide range of surface wettability, from super-hydrophilic to super-hydrophobic. The super-hydrophilic effect is not permanent due to aging (hydrophobic recovery), but the super-hydrophobic is, making such treatment often the last step of creating the desired surface properties.

The deposition of thin films using plasma particles enables the achievement of surface conditions that cannot be achieved with any other known method. Neutral plasma particles with high potential energy are suitable for the application of thin layers, while particles with high kinetic energy are not desirable because they primarily cause etching upon contact with the surface. For the deposition of thin layers, we, therefore, prefer to use plasma with a low density of positive ions, but if this is not possible, the workpieces are always at a floating potential, i.e., away from the electrodes, near which there is a large electric field. Neutral plasma radicals with moderate potential energy condense on the surfaces of materials; some also polymerize, while those with high potential energy can disintegrate, especially if the substrate is heated to a high temperature. Depending on the type of plasma particles and the temperature of the workpieces, compact thin layers or porous and nanostructured layers can be formed on the surfaces of materials. The nanostructured porous layers deposited with plasma radicals are often super-hydrophobic.

Gas plasma is also a source of energetic photons. In most low-pressure plasmas, photons are most abundant at high energy, corresponding to

European patents, EP3802418 for a new method of synthesising carbon nanostructures and EP3757155 for a method of achieving hydrophilicity of fluorinated polymers, were granted.

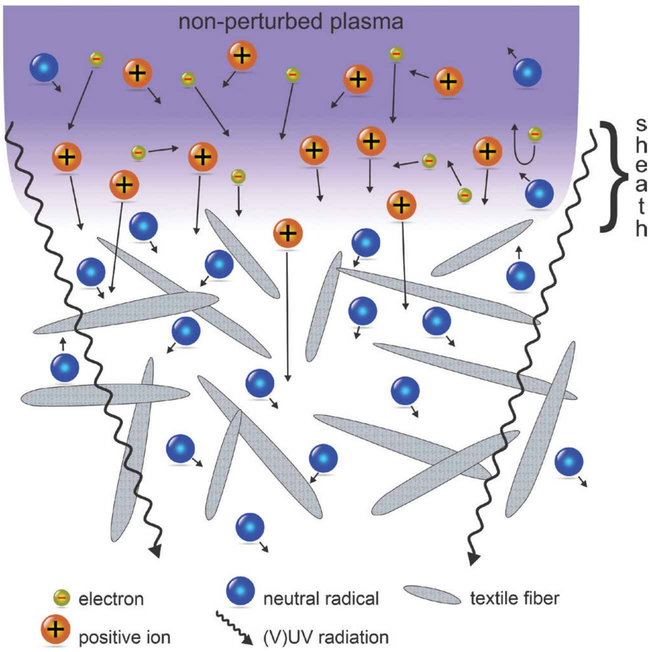

Figure 1: Illustration of the interaction of low-pressure plasma with textiles [1]

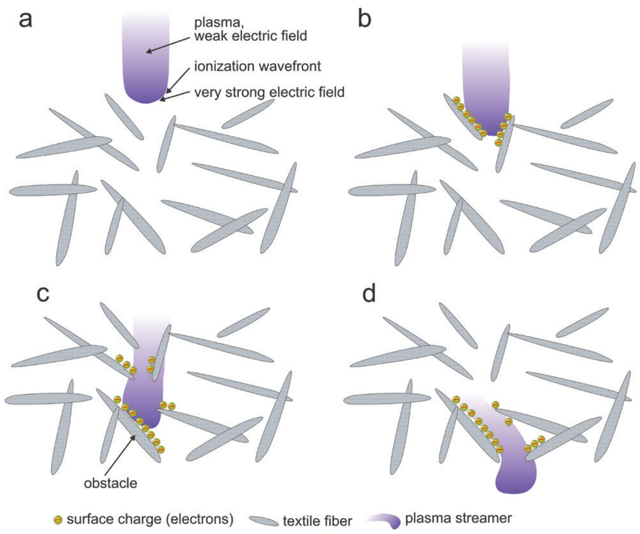

Figure 2: Illustration of the interaction of atmospheric plasma with textiles and the penetration phases of the jet of plasma radicals (a-d) [1]

vacuum ultraviolet (VUV) radiation. Energetic photons in the surface layer of a workpiece cause the splitting of chemical bonds and, thus, the formation of surface radicals, which are suitable for a chemical interaction with gas molecules or their radicals. The energy of VUV photons is greater than any chemical bond in solid materials, which makes the method suitable for processing almost any material.

Surface functionalization is particularly suitable for processing polymeric and other organic materials. Despite the fact that plasma treatment of such materials has been used in industry for decades, the optimization of process parameters still represents both a scientific and a technological challenge. This is especially true for highly porous materials, such as textiles. We explained the mechanism of the interaction of plasma particles with high potential and moderate kinetic energy with textile materials [1]. We explained the key difference between the use of low-pressure and atmospheric plasma for textile processing. During exposure to low-pressure plasma, particles with increased kinetic energy can only react with the surface of a textile, while the fibres inside are treated only with neutral particles with high potential energy since they easily penetrate into the depth of the textile because they do not lose their potential energy due to super-elastic collisions in the gas phase. The best effects are achieved by not placing the textile in the low-pressure plasma at all, but by treating it only with neutral plasma particles. A schematic of the interaction between low-pressure plasma and textiles is shown in Figure 1.

At atmospheric pressure, plasma particles with high potential and/or kinetic energy cannot penetrate deeply into a textile as they are quickly neutralized, relaxed or recombined due to the high frequency of collisions in the gas phase. For this reason, at atmospheric pressure, textiles can only be treated with short pulses of strong plasma, which can penetrate deeply into porous materials as the ionization wavefront provides an adequate density of plasma particles with high potential energy and moderate kinetic energy (Figure 2). The plasma can penetrate between the fibres due to the negative charge on the surface of the fibres, which is due to a higher mobility of electrons compared to positive ions. The surface charge effectively prevents the loss of electrons in the plasma streamer so that it can penetrate deeply into the textile. It can be seen from the comparison of Figures 1 and 2 that low-pressure plasma enables a uniform treatment of all fibres in the textile, while atmospheric plasma only localises it. This type of localized treatment allows a fairly useful functionalization of textiles, as long as the pulses of strong plasma are sufficiently dense and laterally evenly distributed over the surface of the workpiece.

We explained the role of VUV radicals in achieving the super-hydrophilicity of surfaces.

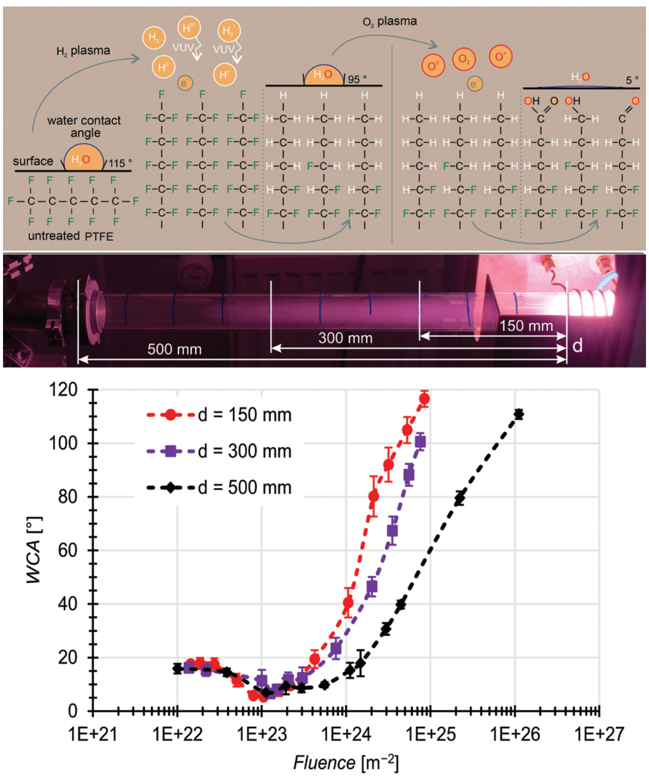

Figure 3: Contact angle of a water droplet on the Teflon surface, first exposed to hydrogen plasma, and then to a weak oxygen plasma at different distances from the radio frequency coil. The mechanism of the interaction of plasma radicals with the surface of the polymer is also shown [4].

Low-pressure plasma (Figure 1) was used to treat cotton textiles before applying a protective coating. Cotton is a natural material with excellent properties, making it the most suitable material for comfortable clothing. The disadvantages of cotton clothing are a relatively poor protection against ultraviolet radiation (when worn outdoors in the summer) and hydrophilicity, which is problematic due to water absorption and, thus, discomfort. A plasma-treated textile was impregnated with zinc acetate and then exposed to the actions of extracts from various plants. The extracts reacted chemically with the thin homogeneous layer of zinc acetate and formed nanoparticles of zinc oxide, which is among the best absorbers of ultraviolet radiation. Nanoparticles on the fibre surface also made the fabric super-hydrophobic, making the water uptake negligible. The textile treated in this way maintains the comfort of wearing cotton clothes while at the same time providing excellent protection against ultraviolet radiation, and the clothes do not get wet. The details of the procedure are explained in a scientific article [2].

The wettability of cellulose and many other polymeric materials for good coating adhesion is rapidly improved by using gas plasma sustained in oxygen. Neutral plasma particles with increased potential energy (for example, oxygen atoms) chemically react and form oxygen functional groups on the surfaces of polymers, which are highly polar, making the polymer hydrophilic. A hydrophilic surface enables a good adhesion of coatings. However, the method is not suitable for processing fluorinated polymers. The bond between carbon and fluorine in Teflon and similar materials is stronger than the bond between carbon and oxygen, so oxygen plasma treatment breaks the bonds between adjacent carbon atoms but not between carbon and fluorine. The result is chemical etching but not surface functionalization of fluorinated polymers with polar oxygen functional groups. A few years ago, we developed a process for achieving super-hydrophilicity of otherwise hydrophobic polymers. The corresponding patent was granted in 2022 [3]. We published the scientific aspects of the technology in an article [4]. A fluorinated polymer is first treated with hydrogen plasma. Low-pressure hydrogen plasma is an extremely powerful source of VUV radiation that easily cleaves the bonds between fluorine and carbon in the surface layer of a workpiece. The hydrogen atoms react with the liberated fluorine to form a strong HF bond. Due to the high flux of H atoms on the surface of the workpiece, the free bonds are filled with hydrogen atoms so that the treatment of the fluorinated polymer with hydrogen plasma enables the formation of a very thin surface layer of polyolefin. The workpiece, which was treated with hydrogen plasma, is treated, in the next step, with oxygen atoms from the oxygen plasma, functionalizing the polyolefin layer with polar groups. An appropriate dose of oxygen atoms enables super-hydrophilicity. It can be seen from Figure 3 that super-hydrophilicity of a material can be achieved in a broad range of atomic oxygen doses. If the dose is too high, the oxygen atoms etch the polyolefin layer, and the opposite effect is achieved. The contact angle of a water droplet, which is a measure of the wettability of materials, is shown in Figure 3 as a function of the dose of atomic oxygen.

Figure 4: Photo of a mobile seed-treatment device. The device is owned by the Slovenian company Interkorn.

Oxygen plasma is also suitable for seed treatment before sowing. Plasma agriculture is one of the modern branches of plasma science, so many research groups around the world are investigating methods for optimizing seed processing. Most scientists conduct experiments in laboratories, but only a few groups report about field experiments and grain yield from gas plasma-treated seeds. Our research group is among the leaders on a global scale and participates in two European projects on the topic of green agriculture. In 2022 we published six scientific articles discussing the scientific aspects of plasma treatment of various seeds. In an article [5], we report on the results of systematic research on fields. We sowed the plasma-treated seeds over two years, comparing the yield with that of the seeds treated previously using techniques that are standard in agricultural practice. We sowed seeds of different wheat varieties and found significant differences with respect to the variety. Field research shows that it is necessary to select different plasma parameters for each wheat variety. For the plasma treatment of seeds, we used a device that is mobile because even for seeds, the high surface energy is not constant, but the hydrophilicity gradually deteriorates. A photo of the device is shown in Figure 4.

Oxygen plasma also enables optimal surface properties of implantable devices, for example, vascular stents. We investigated a method for surface finishing of stainless-steel vascular stents, which provides optimal conditions for the binding of endothelial cells while, at the same time, preventing surface activation of platelets and the proliferation of smooth muscle cells. The latter often leads to complications such as long-term use of antithrombogenic drugs, revision surgeries, increased treatment costs, and a high risk to patients' health. We first deposited a thin layer of titanium to the base material, i.e., stainless steel with appropriate mechanical properties, using the plasma sputtering method. The compact layer was treated with electrochemical method to transform the compact titanium film into a nanostructured titanium oxide with dense layer of nanotubes of about 100 nm in diameter. In the next step, the layer of nanotubes was removed by ultrasound to obtain nanopores, with height of about 20 nm. In the last step, the workpiece was exposed to oxygen plasma to achieve optimal surface chemistry and wettability. Schematic representation of innovative approach for formation of titanium oxide nanopores is presented in Figure 5. Such modification enables improved proliferation of endothelial cells, which present natural antithrombogenic material and at the same time prevents platelet activation and proliferation of smooth muscle cells. The latter is highly relevant to reduce stent induced thrombosis and restenosis. Due to innovative approach the method for fabrication was protected with a patent application, and the scientific aspects were published in an article [6]. Nanostructuring of stainless steel is an extremely interesting research field, as medical devices from stainless-steel are commonly used mainly due to their desired mechanical

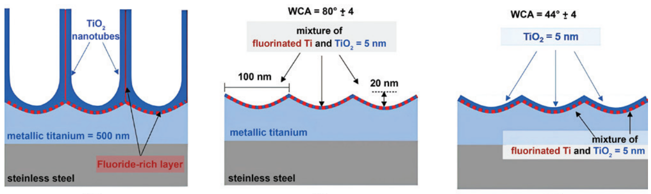

Figure 5: Illustration of an innovative method for optimizing the surfaces of stainless steel stents


EUROPÄISCHES PATENT | EUROPEAN PATENT
BREVET EUROPÉEN

Hiermit wird bescheinigt, dass für die in der Patentschrift beschriebene Erfindung ein europäisches Patent für die in der Patentschrift bezeichneten Vertragsstaaten erteilt worden ist.

It is hereby certified that a European patent has been granted in respect of the invention described in the patent specification for the Contracting States designated in the specification.

Il est certifié par la présente qu'un brevet européen a été délivré pour l'invention décrite dans le fascicule de brevet, pour les États contractants désignés dans le fascicule.

EP3802418 08.06.2022

METHODS FOR FORMING CARBON NANOSTRUCTURED MATERIALS

Patentinhaber | Proprietor(s) of the patent | Titulaire(s) du brevet

Jozef Stefan Institute
Jamova cesta 39
1000 Ljubljana
SI

National University Corporation Tokai National Higher Education and Research System
1, Furo-cho
Chikusa-ku
Nagoya-shi
Aichi 464-8601
JP

António Campinos

München, den | Munich, | Munich, le 08.06.2022

URKUNDE | CERTIFICATE | CERTIFICAT

Figure 6: Decision on the granting of the EU patent for an innovative method for plasma deposition of nanocarbon

properties, however their surface properties are still far from optimal. The scientific aspects of the technological process for surface finishing of stainless-steel have not yet been satisfactorily explained, which we pointed out in a review article [7], where we critically analysed the available literature and provided recommendations for further work.

Non-equilibrium gas plasma is also suitable for the deposition of thin layers of various materials. Years ago, we developed a process for the synthesis of layers of nanostructured carbon with a high content of multi-layered graphene sheets with a thickness of a few nm and a surface area of the order of 10,000 nm. The process is interesting for use in electrochemical converters, which is why we protected it with a patent application. European and Japanese patents were granted in 2022 [8] and we are still waiting for the opinion of the US Patent Office. A copy of the original document, granting an EU patent is shown in Figure 6. Waste plastic is used as a carbon source for the formation of layers of densely distributed graphene sheets. The plastic is placed in a reactor, in which we excite a non-equilibrium gas plasma with a powerful radio frequency discharge in the H-mode of operation. We also place a substrate in the plasma, which is heated to a high temperature upon interaction with plasma species of high potential energy. Plasma particles with high potential and moderate kinetic energy strongly ablate plastic. The resulting radicals are excited in the plasma to states with high potential energy, and the radicals partially dissociate on heated surfaces, forming layers that contain practically only graphene sheets. The sheets can be doped with the desired atoms by exciting the plasma in different gases or gas mixtures. We published the scientific aspects of the technology in an article [9].

To analyse the effects of gas plasma on workpieces, we use cutting-edge techniques for analysing surfaces and thin layers. In addition to analyses of plasma-treated materials, we also perform analyses of other samples. Our laboratory for surface and thin-layer analyses has a 50-year tradition of characterizing surfaces and thin layers. We use the following methods: X-ray photoelectron spectroscopy – XPS, secondary ion mass spectrometry – SIMS, and Auger electron spectroscopy - AES. With the mentioned techniques, we provide analytical support for Slovenian research organizations, academic institutions and industrial partners. The characterization of the above systems is based on complex methods, and the interpretation of the acquired spectra is extremely demanding. We investigated the details of the characterization of thin layers using the ToF-SIMS method. We focused on the influence of the composition of the surface layer on the intensity of individual peaks in the spectra of secondary ions, the increase in the degree of ionization of the material sputtered during bombardment with heavy ions, and the decrease in the surface roughness during depth profiling, which is the result of laterally inhomogeneous etching. These phenomena cause problems in the interpretation of the spectra. An improvement in the quality of depth profiles was achieved by precise dosing of reactive gases into the analysis chamber of the SIMS instrument. We used hydrogen, oxygen, carbon monoxide and acetylene. We determined the optimal pressure range for each gas and compared the effects of different gases. We found that the ionization of metal atoms, their oxides, and molecular fragments increases the most with hydrogen dosing. We checked the effectiveness of the procedure on different samples. In Figure 7, we illustrate the improvement in the resolution of an Fe_2O_3/Fe/Ag/Ni/NiO multilayer structure, prepared with plasma sputtering. The depth profile on the left image was recorded without dosing the reactive gas into the analysis chamber of the SIMS instrument, and on the right image hydrogen was used so that the partial pressure was $7x10^{-5}$ Pa. The improvement of the method was reported in an article [10].

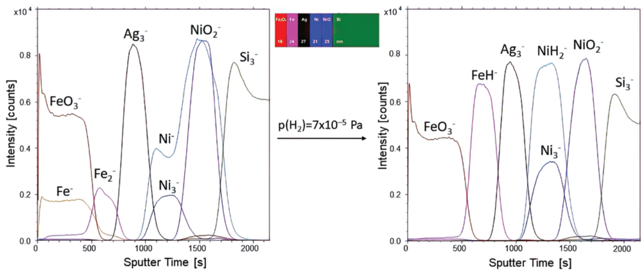

Figure 7: ToF-SIMS depth profile of an FeAgNi multilayer structure etched with a Cs+ ion jet with an energy of 1 keV in a vacuum (left) and in a hydrogen atmosphere at a hydrogen pressure of 7×10^{-5} Pa (right)

We published about 40 scientific articles in the field of thin layer analysis using our techniques. The results of the surface and thin-layer research obtained with our analysis techniques are often upgraded with alternative ones available from our partners in Slovenia and abroad. The combination of different analytical techniques provides an insight into the kinetics of the synthesis of thin layers. In the above article [10], we compared our SIMS and XPS methods with glow-discharge optical emission spectrometry (GDOES). Stainless steel substrates were coated with a thin polymer layer using the plasma polymerization technique.

Some outstanding publications in the past year

1. Primc, Gregor, Zaplotnik, Rok, Vesel, Alenka, Mozetič, Miran, Mechanisms involved in the modification of textiles by non-equilibrium plasma treatment, *Molecules*, 2022, 27, 24, 9064

2. Verbič, Anja, Brenčič, Katja, Dolenec, Matej, Primc, Gregor, Recek, Nina, Šala, Martin, Gorjanc, Marija, Designing UV-protective and hydrophilic or hydrophobic cotton fabrics through *in-situ* ZnO synthesis using biodegradable waste extracts, *Applied Surface Science*, 2022, 599, 153931
3. Lojen, Dane, Zaplotnik, Rok, Primc, Gregor, Mozetič, Miran, Vesel, Alenka, Optimization of surface wettability of polytetrafluoroethylene (PTFE) by precise dosing of oxygen atoms, *Applied Surface Science*, 2022, 598, 153817-1-153817-7
4. Holc, Matej, Mozetič, Miran, Zaplotnik, Rok, Vesel, Alenka, Gselman, Peter, Recek, Nina, Effect of oxygen plasma treatment on wheat emergence and yield in the field, *Plants*, 2022, 11, 19, 2489-1-2489-11
5. Yelkarasi, Cagatay, Recek, Nina, Kazmalni, Kursat, Kovač, Janez, Mozetič, Miran, Urgen, Mustafa, Junkar, Ita, Biocompatibility and mechanical stability of nanopatterned titanium films on stainless steel vascular stents, *International journal of molecular sciences*, 2022, 23, 9, 4595-1-4595-19
6. Benčina, Metka, Junkar, Ita, Vesel, Alenka, Mozetič, Miran, Iglič, Aleš, Nanoporous stainless steel materials for body implants–review of synthesizing procedures, *Nanomaterials*, 2022, 12, 17, 2924-1-2924-15
7. Vesel, Alenka, Zaplotnik, Rok, Primc, Gregor, Paul, Domen, Mozetič, Miran, Comparison of plasma deposition of carbon nanomaterials using various polymer materials as a carbon atom source, *Nanomaterials*, 2022, 12, 2, 246-1-246-15
8. Ekar, Jernej, Panjan, Peter, Drev, Sandra, Kovač, Janez, ToF-SIMS depth profiling of metal, metal oxide, and alloy multilayers in atmospheres of H_2, C_2H_2, CO, and O_2 , *Journal of the American Society for Mass Spectrometry*, 2022, 33, 1, 31-44
9. Kovač, Janez, Ekar, Jernej, Čekada, Miha, Zajíčková, Lenka, Nečas, David, Blahová, Lucie, Wang, Jiang Yong, Mozetič, Miran, Depth profiling of thin plasma-polymerized amine films using GDOES in an Ar-O_2 plasma, *Applied Surface Science,* 2022, 581, 152292

Awards and Appointments

1. Jernej Ekar, ECASIA Student Travel Grant, Limerick, Ireland, European Association on Applications of Surface and Interface Analysis, 19th ECASIA Conference, award for the lecture entitled Reduction of Matrix Effect in ToF-SIMS Depth Profiling via H_2 Flooding
2. Miran Mozetič, WIPO Medal for Inventors (World Intellectual Property Organization)
3. Mark Zver, Best Contribution Recognized by Peers Award, Kamnik, Jožef Stefan International Postgraduate School, for the presentation entitled Creating antimicrobial surfaces via advanced functionalization techniques

Patents granted

1. Ksenija Rener-Sitar, Ita Junkar, Uroš Cvelbar, Miran Mozetič, Method for improving the bonding of dental silicate ceramics with composite cements, SI26082 (A), Slovenian Intellectual Property Office, 29. 04. 2022.
2. Alenka Vesel, Nives Ogrinc, Method for functionalization of polyolefins with simultaneous combination of nitrogen and oxygen functional groups, SI26091 (A), Slovenian Intellectual Property Office, 29. 04. 2022.
3. Rok Zaplotnik, Miran Mozetič, Gregor Primc, Alenka Vesel, Masaru Hori, Methods for forming carbon nanostructured materials, EP3802418 (B1), European Patent Office, 08. 06. 2022.
4. Alenka Vesel, Miran Mozetič, Rok Zaplotnik, Gregor Primc, Nina Recek, Method of increasing the hydrophilicity of a surface of an object of polymer containing fluorine atoms, EP3757155 (B1), European Patent Office, 18. 05. 2022.

INTERNATIONAL PROJECTS

1. COST CA19110; Plasma Applications for Smart and Sustainable Agriculture
   Asst. Prof. Gregor Primc
   Cost Association Aisbl
2. COST CA20114 - PlasTHER; Therapeutical Action of Cold Atmospheric Plasmas
   Asst. Prof. Ita Junkar
   Cost Association Aisbl
3. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
   Asst. Prof. Ita Junkar
   European Commission
4. Low Temperature Plasma Diagnostics and its Applications for Seed Treatment
   Prof. Miran Mozetič
   Slovenian Research Agency
5. Functionalization of Ti-Based Surfaces Using Energy Beams and Plasma for Biomedical Applications
   Asst. Prof. Gregor Primc
   Slovenian Research Agency
6. Promising Eco-Sterilization of Pathogenic Fungi on Seeds Using Reactive Species in Gaseous Plasma
   Prof. Miran Mozetič
   Slovenian Research Agency
7. Facile Preparation of Superhydrophobic Cellulose Nanofibers and Compounding with PLA for Packaging
   Prof. Miran Mozetič
   Slovenian Research Agency
8. Characterization of Oxygen Plasma Sustained with Powerful Discharges
   Prof. Miran Mozetič
   Slovenian Research Agency

9. Catalytic Probes for Characterization of Hydrogen Plasma
Asst. Prof. Gregor Primc
Slovenian Research Agency
10. HE - EUROfusion; WP05: PWIE-1,2,3,_HE-FU, PWIE-4-Accelerator
Prof. Janez Kovač
European Commission
11. HE - AgroServ; Integrated SERvices supporting a sustainable AGROecological transition
Prof. Miran Mozetič
European Commission

RESEARCH PROGRAMMES

1. Thin film structures and plasma surface engineering
Prof. Miran Mozetič
2. Fusion technologies
Asst. Prof. Rok Zaplotnik

R & D GRANTS AND CONTRACTS

1. Structural and surface properties of fibrous membranes for purification and chromatographic separation of biomacromolecules
Asst. Prof. Ita Junkar
2. Ecologically friendly in-situ synthesis of ZnO nanoparticles for the development of protective textiles
Asst. Prof. Gregor Primc
3. Initial stages in surface functionalization of polymers by plasma radicals
Prof. Janez Kovač
4. Alternative approaches to assuring guality and security of buckwheat grain microbiome
Prof. Miran Mozetič
5. Investigation of two-way interactions during plasma treatment of solid wood
Prof. Janez Kovač
6. Cell membrane uptake of bacteria, virions and anorganic particles controlled by membrane mechanics and topology
Asst. Prof. Ita Junkar
7. Removal of selected antimicrobials by plasma-cavitation hybrid technology from water matrices of varying complexity (Causma)
Asst. Prof. Gregor Primc
8. Self-organization of plasma in magnetron sputtering discharges
Prof. Miran Mozetič
9. New startegies for fabrication of biomimetic vascular implants
Asst. Prof. Ita Junkar
10. Innovative procedures for advanced surface properties of medical stainless steel
Dr. Metka Benčina
11. Novel Surface Modification of Dental Prosthetic Replacements by Gaseous Plasma
Dr. Metka Benčina
12. Innovative sensors for real-time monitoring of deposition rates in plasma-enhnced chemical vapour deposition (PECVD) systems
Asst. Prof. Rok Zaplotnik
13. Nanoparticle-reinforced new metal matrix composites manufactured by selective laser melting for tooling industry
Prof. Miran Mozetič
14. A Novel High-strength Aluminium Alloy developed for Selective Laser Melting and Lightweight Applications
Prof. Miran Mozetič
15. Hybrid SLM/DED Additive Manufacturing of Ti6Al4V Advanced Fuel System Components for Aerospace Industry
Asst. Prof. Ita Junkar
16. Miniature fiber-optics sensors for free-radical detection in plasma assisted processe
Asst. Prof. Rok Zaplotnik
17. Carbon nanowalls for future supercapacitors
Prof. Alenka Vesel
18. Selected area functionalization of polymeric components by gaseous plasma
Prof. Miran Mozetič
19. Innovative method for purification of wastewater
Asst. Prof. Gregor Primc
20. Development of safe multifunctional surfaces for catheters to combat biofilms (DemoCat)
Prof. Alenka Vesel
21. Waterborne virus inactivation efficiency of a prototype device combining non-equilibrium plasma and hydrodynamic cavitation
Asst. Prof. Rok Zaplotnik
22. Plasma VUV and UV radiation – a method for successful deactivation of Aflatoxins
Dr. Nina Recek
23. Innovative ECO plasma seed treatment (for sowing and for human and animal diet/nutrition
Dr. Nina Recek
Ministry of Education, Science and Sport
24. Method for preparation of bacteriostatic surfaces on 3D printed medical implants
Dr. Matic Resnik
Ministry of Education, Science and Sport
25. Use of gaseous plasma for higher yields and lower use of antifungal agents in agriculture
Asst. Prof. Ita Junkar
26. Use of gaseous plasma for higher yields and lower use of antifungal agents in agriculture
Asst. Prof. Ita Junkar
Ministry of Agriculture, Forestry and Food
27. Small Services
Prof. Janez Kovač
28. Income from Coowners of Invention for Reimbursement of Costs for IP Protection in the Case of EVT140_Mozetič_Carbon Nanowall
Prof. Miran Mozetič
Nagoya University
29. EVT770_Mozetič_CNW2_Reimbursement of the Costs for Patent; Income from Coowners of Invention for Reimbursement of Costs for IP Protection in the Case of EVT770_Mozetič_CNW2
Prof. Miran Mozetič
Nagoya University

NEW CONTRACTS

1. Small Services
Prof. Janez Kovač
2. Co-finanicing of L-project L2-1834 Carbon nanowalls for future supercapacitors
Prof. Alenka Vesel
Iskra, d. o. o.
3. Innovative sensors for real-time monitoring of deposition rates in plasma-enhanced chemical vapour deposition (PECVD) systems
Asst. Prof. Rok Zaplotnik
Iskra, d. o. o.
4. L-project co-financing: Innovative method for purification of wastewater
Asst. Prof. Gregor Primc
Induktio d. o. o.
5. L-project co-financing: Selected area functionalization of polymeric components by gaseous plasma
Prof. Miran Mozetič
Elvez, d. o. o.
6. Development of safe multifunctional surfaces for catheters to combat biofilms (DemoCat)
Prof. Alenka Vesel
Tik d. o. o.
7. Waterborne virus inactivation efficiency of a prototype device combining non-equilibrium plasma and hydrodynamic cavitation
Asst. Prof. Rok Zaplotnik
Kolektor Group d. o. o.
8. Plasma VUV and UV radiation - a method for successful deactivation of Aflatoxins
Dr. Nina Recek
Interkorn d. o. o.

VISITORS FROM ABROAD

1. Primož Eiselt, Franz Resch, Plasmait, Lannach, Austria, 23 April 2022
2. Prof. Mahendra K. Sunkara, Louisville University, Louisville, Kentucky, USA; Vasanthi Sunkara, Advanced Energy Materials, LLC, Louisvile, Kentucky, USA, 2 June 2022
3. Prof. Petr Smolka, dr Ilona Sergeevna, Faculty of Technology, Tomas Bata University in Zlin, Zlin, Czech Republic, 20–24 June 2022
4. Jan Sezemský, Czech Technical University in Prague, Prague, Czech Republic, 12–30 September 2022, 17–21 October 2022, 28 November–2 December 2022
5. Prof. Sanja Ercegović Ražić, Nikša Krstulović, Institute of Physics, Zagreb, Croatia, 11 October 2022
6. Claudia Zoani, ENEA Centro Ricerche Casaccia, Santa Maria di Galeria, Italy, 25 October 2022
7. Danilo Krstić, Vladimir Rajić, Vinča Nuclear Research Institute, Belgrade, Serbia, 5–9 December 2022
8. Jon Simonnæs, John Lyder, Provida Medical, Oslo, Norway, 6–7 December 2022
9. Prof. Katsuhisa Kitano, Takashi Kunizawa, Osaka University, Osaka, Japan, 4–8 December 2022

STAFF

Researchers
1. Dr. Metka Benčina
2. Asst. Prof. Ita Junkar
3. Prof. Janez Kovač
4. Prof. Miran Mozetič
5. Asst. Prof. Gregor Primc
6. **Prof. Alenka Vesel, Head**
7. Asst. Prof. Rok Zaplotnik
8. **Postdoctoral associates**Dr. Matej Holc
9. *Dr. Marian Lehocky, left 01.04.22*
10. *Dr. Dane Lojen, left 16.11.22*
11. Dr. Nina Recek
12. *Dr. Matic Resnik, left 01.09.22*

Postgraduates
13. Jernej Ekar, B. Sc.
14. Domen Paul, B. Sc.
15. Pia Starič, B. Sc.
16. Mark Zver, M. Sc.

Technical officers
17. Tatjana Filipič, B. Sc.
18. Maja Šukarov, B. Sc.

Technical and administrative staff
19. Janez Trtnik