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 ultra-high-vacuum environment, vacuum optoelectronics, and basic research in the field of surface and thin-film characterization by electron spectroscopy techniques.

Head:
Prof. Miran Mozetič

A variety of low-pressure gaseous discharges have been used to create non-equilibrium plasma suitable for the treatment of solid materials. The research team has specialized in high-frequency discharges. Both radiofrequency and microwave generators are used to create gaseous plasma with suitable characteristics. Radio-frequency discharges are usually coupled inductively in order to take advantage of an electrode-less configuration. The absence of strong electrical fields in such discharges prevents the sputtering of solid materials by energetic ions and thus the preservation of the original surface properties of the discharge chambers. Such discharges are often used when homogeneous plasma in a rather large volume needs to be created and the low kinetic temperature of the neutral gas needs to be preserved. Microwave discharges, on the other hand, are used where dense plasma should be concentrated into a rather small volume. Plasma driven by microwave generators is created either in a resonant cavity with standing microwaves or in narrow tubes taking advantage of the surface waves propagating along the tube. The first configuration is characterized by extremely high resonant voltages localized close to the centre of the resonant cavity, while in the other configuration the peak voltage is moderate. Both configurations of microwave discharges never create very cold plasma so they are suitable for the treatment of materials at elevated temperatures. Plasma created by surface waves in narrow long tubes is cooled upon adiabatic expansion due to a pressure gradient along the continuously pumped narrow glass tubes so it is suitable as a convenient source of cold radicals.

Figure 1: Plasma is created using an inductively coupled RF discharge

Gaseous plasma contains a variety of particles that are used for the treatment of solid materials. Plasma is usually created in gases such as oxygen, hydrogen, nitrogen and ammonia. Gaseous molecules dissociate and partially ionize in plasma so the concentration of neutral as well as ionized reactive particles is orders of magnitude larger than in the equilibrium state of the gas at the chosen temperature. Plasma particles are chemically very reactive and often interact with surfaces of solid materials, even at room temperature. Since the kinetic energy of particles is low the interaction is essentially chemical. The interaction between the plasma particles and solid materials causes a modification of the surface properties, including surface functionalization, low-temperature etching and the spontaneous growth of nanostructures on originally flat surfaces.

Although oxygen plasma is nowadays widely used for the surface modification of polymers and other hydrogenated carbon materials the exact mechanisms involved during the interaction of various oxygen reactive particles with organic materials is still far from being well understood. To enlighten this hot topic of current science we organized a specialized workshop entitled "69th IUVSTA workshop on modification of organic materials by excited radicals created in non-equilibrium oxygen plasma". The Workshop was supported by International Union for Vacuum Science, Technique and Applications (IUVSTA) and took place in the small village of Cerklje na Gorenjskem close to Ljubljana International Airport. Invited participants presented different views on this complex phenomenon and agreed that a lot of work will have to be performed in the future in order to understand the roles that each type of reactive particles play upon the treatment of organic materials with oxygen plasma. The participants agreed that

A novel method for determining the O-atom density in weakly ionized oxygen plasmas and the afterglows from catalytic probe signals has been developed and applied for the optimization of our sensors, thus expanding their applicability to gases such as carbon dioxide.

synergistic effects should not be neglected and stressed the need to have independently adjustable fluxes of specific radicals onto the surfaces of organic materials.

The functionalization of polymer materials with polar functional groups is usually performed by a treatment with non-equilibrium oxygen plasma. Surfaces of many widely used polymers are saturated with functional groups by using either positively charged molecular and atomic oxygen ions or neutral reactive species such as atoms in the ground and metastable states. Since the flux of atoms in the ground state is of the highest importance for the proper functionalization of polymer materials we developed a novel method for the determination of the O-atom density in weakly ionized oxygen plasmas and afterglows from catalytic probe signals using the right model based on physical formalism. The probes are also capable of measuring the O-atom density in plasma created in other gases such as carbon dioxide. The treatment of polymers by such radicals allows for a uniform distribution of functional groups on the entire surface of the selected polymer materials. In many practical applications, however, only selected areas should be functionalized. Since methods for localized functionalization at the micrometre scale are not yet known we invented an opposite technique: The polymer sample is first functionalized by plasma treatment and then selected areas are exposed to energetic electrons from an appropriate electron gun. Electrons heat the surface spot and de-functionalize it since the functional groups are not stable at elevated temperatures. The electron jet raster on the surface and thus a selected area becomes free from polar functional groups. The appropriate US patent was granted in August 2012.

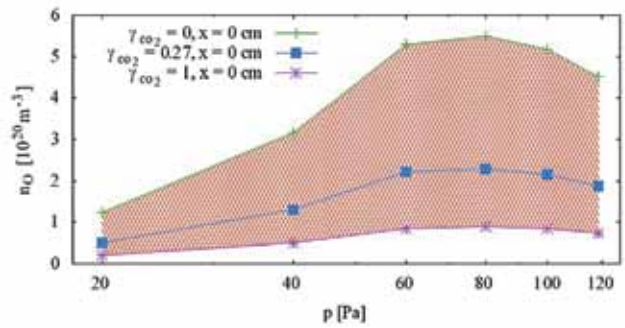

Figure 2: Density of O-atoms in the early afterglow of plasma created in CO_2. Dashed area represents possible values taking into account extreme values of the recombination coefficients and the middle curve the most probable value.

Surface functionalization is an appropriate method for the modification of materials used in medicine. The method has been successfully applied to improve the biocompatibility of vascular grafts made from knitted polymer fibres. Systematic research showed that insufficient biocompatibility of this material causes the activation of blood platelets and the release of enzymes responsible for triggering thrombotic reactions. The activation of blood platelets could be minimized using reactive particles from oxygen plasma to modify the surface properties of artificial blood vessels. The properly selected fluxes of both positively charged and neutral radicals allow for a decrease of highly activated forms of blood platelets by well over an order of magnitude, with which the risk for undesired thrombotic reactions is also significantly reduced.

A US patent protecting our method for the local functionalization of polymer materials was granted in August 2012.

Plasma treatment is also a suitable method for the modification of cellulose materials. The effect of interaction between the plasma radicals and these materials is several-fold. The reactive particles cause total oxidation of impurities that are likely to appear on cellulose. The result of this interaction is the removal of almost all organic impurities. Next, the treatment by oxygen plasma causes the formation of dangling bonds and functional groups of high polarity. This effect is due to the interaction of hard UV radiation and reactive predominantly neutral oxygen radicals with cellulose materials. Furthermore, oxygen radicals cause controlled inhomogeneous etching of cellulose fibres and thus the formation of nanostructured surfaces. All there effects reflect in excellent adhesion of coatings that are deposited on plasma-treated cellulose in order to modify the surface properties. In fact, the combination of a plasma treatment followed by the deposition of highly hydrophobic thin films by the sol-gel method allows not only for super-hydrophobic properties but also for oleo-phobic and thus self-cleaning properties.

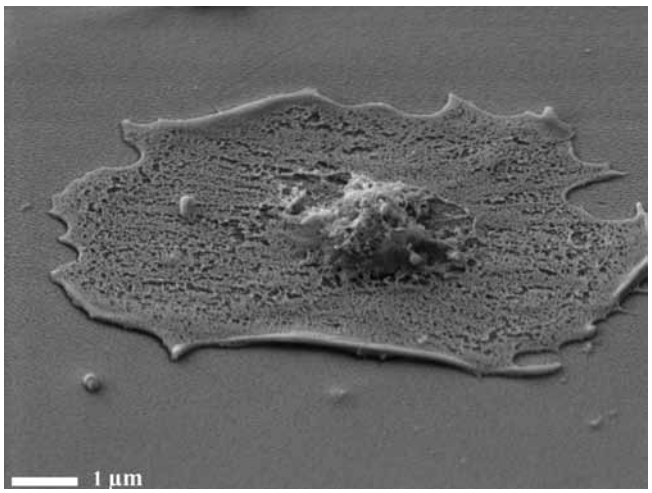

Figure 3: SEM image of a well-activated spread blood platelet

Highly non-equilibrium gaseous plasma created in gases such as oxygen, carbon dioxide and sulphur dioxide is also suitable for the synthesis of metal oxide nanoparticles. Various metals form oxides of different morphology upon exposure to a plasma environment. The hematite nanostructures gain different shapes upon treatment with oxygen plasma with different parameters. The choice of shapes include nano-needles, a dense forest of nano-wires as well as nano-walls, all depending on fluxes of different particles created in an oxygen plasma onto the surface of substrates. These structures have interesting photochemical properties so they are suitable for manufacturing nanowire array electrodes for water splitting.

The European project PlasmaNice: Atmospheric plasmas for nanoscale industrial surface processing, funded under 7th FP was accomplished successfully. This project lasted for four years and involved 15 European partners

from research organizations and industry. The result of the project is a new technology for the industrial in-line deposition of functional coatings on paper and plastic substrates for packaging assisted by atmospheric plasmas as well as corresponding production line. Our group performed precise surface characterization of plasma deposited sol-gel coatings using the XPS, AFM and ToF-SIMS methods. We determined the correlation between the plasma parameters, the degree of surface functionalization and the thickness of the deposited coatings. 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 velocity, which has a great potential for industrial applications.

The characterization of surfaces and interfaces, layered structures and nanomaterials requires the application of advanced surface-sensitive analytical techniques. In our department X-ray photoelectron spectroscopy (XPS), Auger electron spectroscopy (AES) and atomic force microscopy (AFM) have been used successfully, both for basic research and for the characterization of technological samples. Our research group is recognized worldwide as a leading group in the research field of the depth profiling of thin films and multilayers at a high depth resolution.

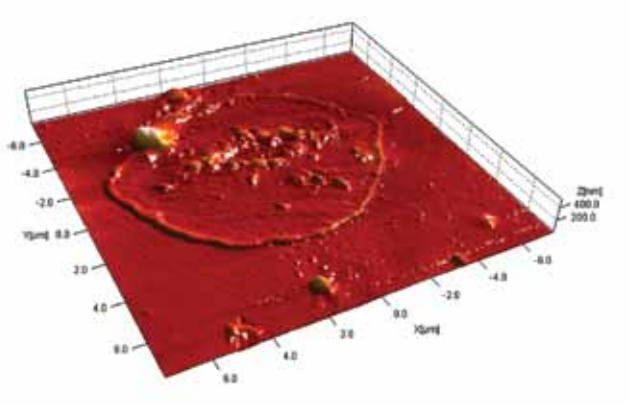

Figure 4: AFM image of a fully spread blood platelet

A new method, time-of-flight secondary ion mass spectroscopy (ToF-SIMS), has been introduced in our laboratory. It is the only instrument of this type in Slovenia. This advanced method enables a precise characterization of the chemical structure of surfaces of organic materials like polymers and biomaterials, as well as a variety of inorganic materials like metals, semiconductors, composites, nanostructure materials, etc. The ToF-SIMS method is based on the bombardment of a sample with clusters of Bi ions, subsequent desorption of ionized surface molecules and ionized atomic clusters, followed by a mass analysis of the desorbed species. The mass analyser determines the masses of the ions on the basis of the time of flight of ions in a multichannel mode, which allows for fast analyses. The new ToF-SIMS spectrometer operates in a ultrahigh vacuum and allows for the chemical imaging of solid surfaces with a lateral resolution of 50 nm and mass spectroscopic analysis up to 10,000 mass units with a high mass resolution. The characterization depth is only about 1 nm, which makes this method one of the most surface-sensitive ones. Unlike most other surface-sensitive techniques it is also a suitable technique for a determination of the hydrogen distribution on the sample surface. This new analytical equipment will allow us to follow new trends in the development, treatment and characterization of new materials as well as to synthesize our own advanced materials.

The activation of blood platelets is reduced dramatically on polymer materials treated by oxygen plasma.

In the field of thin-film physics we continued with a systematic study of interfacial reactions in different multi-layered systems like Al/Ti, Ni/Ti and Si/C composed of 20–50-nm-thick layers and exposed to different activation mechanisms like ion beam mixing, thermal treatment or laser illumination. The applied processing can be interesting for the fabrication of tightly bond multi-layered structures with gradual changes of their composition and properties. Interactions induced in Al/Ti multilayers by the implantation of high-energy Ar^+ ions were studied by XPS and AES in collaboration with the Institute for Nuclear Sciences from Vinča, Serbia. It was found that ion irradiation induced a progressive intermixing of the multilayer constituents and Al–Ti nanoalloying. The resulting nanocrystalline structure had a graded composition with non-reacted or interdiffused Al and Ti, as well as γ-AlTi and $AlTi_3$ intermetallic phases. Most intense reactivity was observed around the mid-depth of the multilayers, where most energy was deposited by the impact ions. Using the XPS spectroscopic method we studied the electronic properties and the ratio of the valence states of Ni^{3+}/Ni^{2+} in electrochromic coatings deposited from $N_{1-x}O$ pigment/NiO_xH_y dispersion in collaboration with National Institute of Chemistry, Ljubljana. These coatings demonstrate a large potential for manufacturing plastic film based electrochromic devices, providing transmitted-light modulation. Low-temperature curing enabled the deposition of pigment coatings on conducting polymer films.

Figure 5: The cover page of the journal Chemical Communications advertises our paper U. Cvelbar et al, Sub-oxide-to-metallic uniformly-nanoporous crystalline nanowires by plasma oxidation and electron reduction.

Our three-chamber UHV system with a quadrupole mass spectrometer was upgraded to allow for very sensitive and quantitative gas analyses. It was applied successfully to measure the gas release from various organic and inorganic materials. The problem of water adsorption and re-adsorption in the UHV system that causes the main inaccuracy was solved by keeping the analytical part of the system at 120°C. The performance has been tested for the quantitative outgassing rate measurement of the water from glass samples kept at various temperatures as well as for newly synthesized organic rigid foams that may be applied in advanced thermal insulations. The new open-pore rigid organic foams that are stable at temperatures up to 200°C were synthesized at the

A new analytical method Secondary Ion Mass Spectroscopy - TOF-SIMS was introduced for the advanced characterization of the surface chemical structure of organic materials.

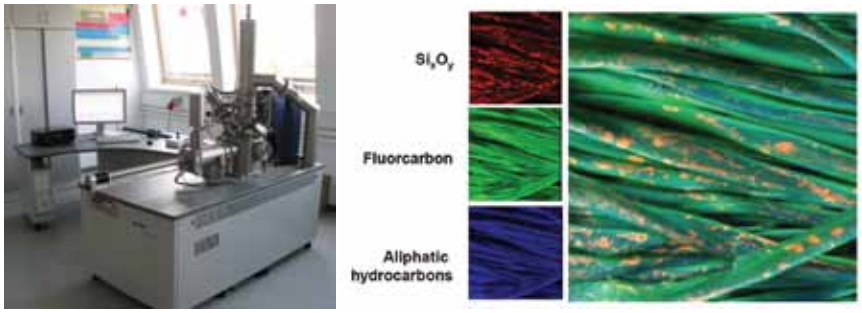

Figure 6: A new ToF-SIMS spectrometer for the characterization of the chemical structure of organic materials has been installed (left image). It allows for the chemical imaging of surfaces with a lateral resolution of 50 nm and mass spectroscopy analysis up to 10,000 mass units with a high mass resolution. TOF-SIMS images of the chemical composition on the surface of cotton fibres after the deposition of silane-based coatings with F-based species (right).

After four years the EU project PlasmaNice, involving 15 partners, successfully finished with the development of new equipment and technology for the industrial deposition of silane-based functional coatings on paper and plastic packaging materials assisted by atmospheric plasmas.

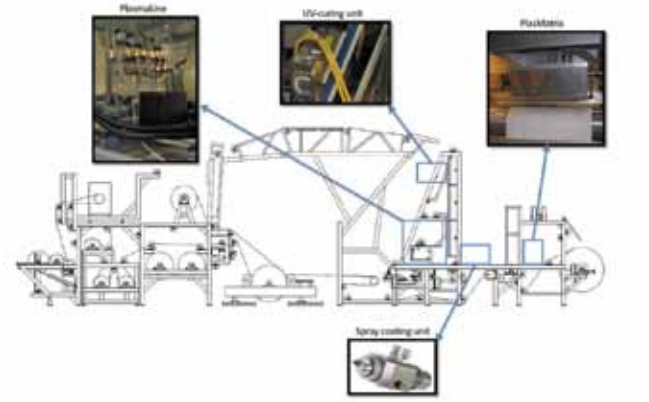

Figure 7: Industrial pilot line for the treatment of packaging materials like paper and plastics at the Technical University Tampere (TUT) in Finland, where new equipment for the deposition of hybrid silane-based coatings was installed, based on air plasma. Collaboration in the PlasmaNice EU project was coordinated by dr. J. Kovač.

Melamin Company from Kočevje (Slovenia). Using our very sensitive techniques, developed previously, it was revealed that they have an extremely low outgassing rate. Their thermal conductivity equals to 5 mW/(m K) at low pressure. This thermal conductivity was increasing slowly with the pressure of argon up to 10 mbar, which reveals their very small average pore diameter. Since the density of these foams is acceptable at about 50 kg/m^3 they are extremely attractive as the core material in vacuum insulating panels (VIP). A literature survey reveals that these foams are the only organic material that is stable inside a VIP for decades. Novel VIP solutions are the most promising approaches to energy-efficient devices and buildings.

Our formerly revealed physical picture that electron field emission from graphite platelets being only a few nanometres thick is responsible for the stable operation of gas surge arresters has been applied and upgraded. By a well-planned series of experiments the breakdown voltage drift with time in gas surge arresters has been explained and stabilized for unipolar or bipolar pulses. By using a proper design of inter-electrode gap, by proper gas mixture and subsequent thermal treatment of the arrester, an extremely stable breakdown voltage was achieved in bipolar breakdown events. Our industrial partner Iskra Zaščite has already launched a new generation of reduced size and stable breakdown voltage gas-surge arresters on the global market. Besides the extremely high stability, the advantage of the new gas surge arrester is a substantially reduced volume compared to competing products.

Some outstanding publications in the past year

1. Zaplotnik, R., Vesel, A., Mozetič, M.: A fiber optic catalytic sensor for neutral atom measurements in oxygen plasma. Sensors, 2012, vol. 12, no. 4, pp. 3857–3867
2. Vasiljević, ., Gorjanc, M., Tomšič, B., Orel, B., Jerman, I., Mozetič, M., Vesel, A., Simončič, B.: The surface modification of cellulose fibres to create super-hydrophobic, oleophobic and self-cleaning properties. Cellulose (Lond.), 2012, vol. 20, no. 1, pp. 277–289
3. Cvelbar, U., Levchenko, I., Filipič, G., Mozetič, M., Ostrikov, K.: Plasma control of morpho-dimensional selectivity of hematite nanostructures. Appl. phys. lett., 2012, vol. 100, no. 24, pp. 243103-1-243103-6
4. Modic, M., Junkar, I., Vesel, A., Mozetič, M.: Ageing of plasma treated surfaces and their effects on platelet adhesion and activation. Surf. coat. technol., 2012, vol. 213, pp. 98–104
5. Mihelčič, M., Jerman, I., Švegl, F., Šurca Vuk, A., Slemenik Perše, L., Kovač, J., Orel, B., Posset, U.: Electrochromic Ni1-xO pigment coatings and plastic film-based Ni1-xO/TiO2 device with transmissive light modulation. Sol. energy mater. sol. cells. Dec. 2012, vol. 107, pp. 175–187
6. Milosavljević, M., Stojanović, N., Peruško, D., Timotijević, B., Toprek, D., Kovač, J., Dražić, G., Jeynes, C.: Ion irradiation induced Al-Ti interaction in nano-scaled Al/Ti multilayers. Appl. surf. sci., 2012, vol. 258, no. 6, pp. 2043–2046

Awards and appointments

1. Dr. Martina Modic; Award for the best Poster at the 14th Joint Vacuum Conference, Poster with title “Shear stress and platelet adhesion on plasma treated polymer surfaces”.

Organization of conferences, congresses and meetings

1. IUVSTA Workshop, Cerklje na Gorenjskem, Slovenia, 9–12. 12. 2012

Patents granted

1. Miran Mozetič, Alenka Vesel, Uroš Cvelbar, Method and device for local functionalization of polymer materials, US8247039 (B2), United States Patent and Trademark Office, 21.8.2012..
2. Gregor Primc, Miran Mozetič, Method for dynamically controlling the density of neutral atoms in a plasma vacuum chamber and a device for the processing of solid materials by using this method, SI23626 (A), Urad RS za intelektualno lastnino, 31.7.2012..
3. Rok Zaplotnik, Alenka Vesel, Miran Mozetič, Device for high-frequency gas plasma excitation, SI23611 (A), Urad RS za intelektualno lastnino, 31.7.2012.

INTERNATIONAL PROJECTS

1. Development of a vacuum measurement method with respect to vacuum glazing
   AGC Glass Europe
   Dr. Vincenc Nemanič
2. 7. FP - PlasmaNice: Atmospheric plasmas for nanoscale industrial surface processing
   European Commission
   Asst. Prof. Janez Kovač
3. 7. FP - EURATOM: deuterium interation kinetics metals relevant to iter or demo - 1.4.4. - FU; Annex 3 to Contract 3211-08-000102, FU07-CT-2007-00065
   Ministry of Higher Education, Science and Technology
   Dr. Vincenc Nemanič
4. 7. FP - EURATOM: Removal of deposits by neutral oxygen and nitrogen atoms - 1.4.2.-FU; Annex 3 to Contract 3211-08-000102, FU07-CT-2007-00065
   Ministry of Higher Education, Science and Technology
   Prof. Miran Mozetič
5. 7. FP - EURATOM, MHEST Association: Application of neutral atoms for fuel removal in gaps; WP11-PWI-02-04-01/PS
   Ministry of Higher Education, Science and Technology
   Prof. Miran Mozetič
6. FP - MHEST ASSOCIATION: Investigation of growth of fuzz on tungsten under high heath loads and exposure to hydrogen plasma
   Ministry of Higher Education, Science and Technology
   Prof. Miran Mozetič
7. FP - EURATOM, MHEST Association: deuterium retention and release from metal surfaces - 1.4.4.-FU
   Ministry of Education, Science and Sport
   Dr. Vincenc Nemanič
8. FP - EURATOM, MHEST Association: Extending knowledgebase on fuel release (and retention) of Be-containing mixed materials; WP12-IPH-A01-3-04/PS-1
   Ministry of Education, Science and Sport
   Dr. Vincenc Nemanič
9. COST MP1101: Biomedical applications of atmospheric pressure plasma technology
   COST Office
   Asst. Prof. Uroš Cvelbar
10. NATO Planning Grant; SfP 984555: Atmospheric pressure plasma jet for neutralisation of CBW (Chemical Biological Weapons)
    NATO
    Asst. Prof. Uroš Cvelbar
11. Thermoionic energy conversion
    Public Research Agency
    Dr. Vincenc Nemanič
12. Nanowires for photoelectrochemical energy conversion and water splitting
    Public Research Agency
    Asst. Prof. Uroš Cvelbar
13. Plasma synthesis and application of nanowalls
    Public Research Agency
    Asst. Prof. Uroš Cvelbar
14. Plasma synthesis and deposition of quantum dots
    Public Research Agency
    Asst. Prof. Uroš Cvelbar
15. Determination of interdiffusion coefficients in nano-layered structures by high resolution Depth Profiling
    Public Research Agency
    Asst. Prof. Janez Kovač
16. Plasma diagnostics for applied research of dusty plasmas with nanoparticles
    Public Research Agency
    Asst. Prof. Uroš Cvelbar
17. Plasma treatment of titanium stents
    Public Research Agency
    Asst. Prof. Uroš Cvelbar
18. Investigation of microwave discharges applicable in biomedicine and nanotechnology
    Public Research Agency
    Prof. Miran Mozetič
19. Plasma-assisted Synthesis of nano-objects
    Public Research Agency
    Asst. Prof. Uroš Cvelbar
20. Formation of nanocomposite thin films in dusty magnetized plasma
    Public Research Agency
    Asst. Prof. Alenka Vesel
21. Hydrogen interaction with W/Be films relevant for fusion reactors
    Public Research Agency
    Dr. Vincenc Nemanič

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. Use of nanoparticles as additives in lubricants and in tribology
   Asst. Prof. Janez Kovač
2. Near-net shape nanoparticle-reinforced polymer-composites for highly-loaded advanced mechanical components with superior tribological performance
   Asst. Prof. Janez Kovač
3. Organic-inorganic thin film structures for electronics components
   Asst. Prof. Janez Kovač
4. Multifunkctional nanocomposite coatings and paints
   Asst. Prof. Janez Kovač
5. Research and development of integrated overvoltage protection devices based on gaseous discharger toward a reliable miniature technical solution
   Dr. Vincenc Nemanič
6. Development of advanced processes for attending high efficient nano modified textile materials
   Prof. Miran Mozetič
7. Synthesis and functionalization of composite nanobeads for early diagnosis of neurodegenerative diseases
   Asst. Prof. Alenka Vesel
8. Superhydrophilicity of surfaces and its application in technological processes for industrial application
   Asst. Prof. Uroš Cvelbar
9. Ignition and self-extinguishing of arc in a gas surge arrester at high overvoltages
   Dr. Vincenc Nemanič
10. Plasma treatment of vascular grafts
    Prof. Miran Mozetič
11. Multifunctional nanostructured films for artificial implants - corrosion and tribo-corrosion processes
    Asst. Prof. Janez Kovač
12. Synthesis of nanowires for regenerative energy cells
    Asst. Prof. Uroš Cvelbar
13. Colour, absorption and protective nanolayer coatings for aluminium alloy
    Asst. Prof. Janez Kovač
14. Functionalization of biomedical samples by thermodynamic non-equilibrium gaseous plasma
    Prof. Miran Mozetič
15. Toward ecologically benign alternative for cleaning of delicate biomedical instruments
    Asst. Prof. Alenka Vesel
16. Preparation of hemocompatible polymeric surfaces for biomedical applications
    Dr. Ita Junkar
17. Biopackaging, EUREKA: Development of bioactive packaging
    Prof. Miran Mozetič

NEW CONTRACTS

1. Nanowire synthesis for regenerative energy cells
   Kolektor Group, d.o.o.
   Asst. Prof. Uroš Cvelbar

2. Functionalization of biomedical samples by thermodynamically non-equilibrium gaseous plasma
   BIA Separations
   Prof. Miran Mozetič
3. Toward ecologically bening alternative for cleaning of delicate biomedical instruments
   Ekliptik, d.o.o.
   Asst. Prof. Alenka Vesel

VISITORS FROM ABROAD

1. Prof. Satomi Tajima, Nagoya University, Japan, 19.–24. 2. 2012
2. Prof. Hitoshi Watanabe, Nagoya University, Japan, 19.–24. 2. 2012
3. Prof. Kostyantyn Ostrikov, CSIRO, Sydney, Australia, 16. 4.–22. 7. 2012
4. Dr. Tonči Tadić, Rudjer Bošković Institute, Zagreb, Croatia, 24. 4. 2012
5. Dr. Nikola Radič, Rudjer Bošković Institute, Zagreb, Croatia, 24. 4. 2012
6. Dr. Hans Georg Cramer, ION TOF, Münster, Germany, 7.–18. 5. 2012
7. Paul Brunet, University of Toulouse, Toulouse, France, 14.–20. 5. 2012
8. Dr. Davor Peruško, Vinča Institute of Nuclear Science, Belgrade, Serbia, 20.–26. 5. 2012
9. Prof. Sabu Thomas, Mahatma Gandhi University, Kottayam, Kerala, India, 30.–31. 5. 2012
10. Dr. Kinga Kutasi, Research Institute for Solid State Physics, Budapest, Hungary, 1.–7. 7. 2012
11. Dr. Francisco L. Tabares Vazques, CIEMAT, Madrid, Spain, 13.–22. 8. 2012
12. Daniel Alegre, CIEMAT, Madrid, Spain, 19. 8.–9. 9. 2012
13. Cedric Labay, University of Barcelona, Barcelona, Spain, 8.–23. 9. 2012
14. Dr. Richard Clergereaux, University Paul Sabatier, Toulouse, France, 22.–27. 10. 2012
15. Dr. Cristian P. Lungu, National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania, 5.–9. 11. 2012
16. Dr. Corneliu Porosnicu, National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania, 5.–9. 11. 2012
17. Dr. Sanghoo Park, KAIST, Daejeon, Republic of Korea, 2.–13. 12. 2012
18. Dr. Kinga Kutasi, Research Institute for Solid State Physics, Budapest, Hungary, 5.–13. 12. 2012
19. Prof. Masaru Hori, Nagoya University, Nagoya, Japan, 5.–13. 12. 2012
20. Prof. Wonhoe Choe, KAIST, Daejeon, Republic of Korea, 9.–13. 12. 2012
21. Prof. David Ruzic, University of Illinois at Urbana-Champain, USA, 12.–13. 12. 2012
22. Dr. Sanja Medenica, Institute for public health of Montenegro, Podgorica, Montenegro, 17.–24. 12. 2012
23. Dr. Danijela Vujošević, Institute for Public Health of Montenegro, Podgorica, Montenegro, 17.–24. 12. 2012

STAFF

Researchers
1. Asst. Prof. Uroš Cvelbar
2. Asst. Prof. Janez Kovač
3. **Prof. Miran Mozetič, Head**
4. Dr. Vincenc Nemanič
5. Asst. Prof. Alenka Vesel
6. Dr. Bojan Zajec

Postdoctorial associates
7. Dr. Aleksander Drenik
8. Dr. Kristina Eleršič
9. Dr. Ita Junkar
10. Dr. Martina Modic
11. Dr. Rok Zaplotnik

Postgraduates
12. Gregor Filipič, B. Sc.
13. Gregor Jakša, B. Sc.
14. Metod Kolar**
15. Borut Praček, B. Sc.
16. Gregor Primc, B. Sc.
17. Nina Recek, B. Sc.
18. Marko Žumer, B. Sc.

Technical officers
19. Gregor Avbelj, B. Sc.
20. Tatjana Filipič, B. Sc.

Technical and administrative staff
21. Ružica Bolte, retired 24.07.12
22. Urška Kisovec, B. Sc.
23. Janez Trtnik

** postgraduate financed by industry

BIBLIOGRAPHY

Original Scientific Article

1. Oleg Baranov, Maxim Romanov, Jinghua Fang, Uroš Cvelbar, Kostya Ostrikov, "Control of ion density distribution by magnetic traps for plasma electrons", *J. appl. phys.*, vol. 112, no. 7, pp. 073302-1-073302-10, 2012.
2. Árpád Barna, Sandor Gurban, László Kotis, János L. Lábár, Attila Sulyok, Attila L. Tóth, Miklós Menyhárd, Janez Kovač, Peter Panjan, "Growth of amorphous SiC film on Si by means of ion beam induced mixing", *Appl. surf. sci.*, vol. 263, pp. 367-362, 2012.
3. Boris Chernomordik, Harry B Russell, Uroš Cvelbar, Jacek B. Jasinski, Vivekanand Kumar, Todd Deutsch, Mahendra K. Sunkara, "Photoelectrochemical activity of as-grown, $\alpha - Fe_2O_3$ nanowire array electrodes for water splitting", *Nanotechnology (Bristol)*, vol. 23, no. 19, pp. 194009-1-194009-9, 2012.
4. Lenka Chvátalova, Roman Čermak, Aleš Mraček, Ondrej Grulich, Alenka Vesel, Petr Ponížil, Antonín Minařík, Uroš Cvelbar, Lubomír Beníček, Petr Sajdl, "The effect of plasma treatment on structure and properties of poly(1-butene) surface", *Eur. Polym. J.*, vol. 48, no. 4, pp. 866-874, 2012.
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