iPlasmaNano-X

September 15-20, 2019

Plava Laguna

Poreč Croatia

http://iplasmanano2019.com/

Keynote: 40 min including questions

IT: 30 min including questions (25+5 min)

Short talks: 15 min including questions (12+3 min)

Poster Session:

The posters will be presented throughout the whole conference in the conference hall.
The format of the posters is A0 Portrait

Sunday 15-Sept		
14:00	Reception-registration	
17:00 – 17:15	**CONFERENCE OPENING CEREMONY& OPENING SESSIONS** **Welcome: E. Kovacevic, J. Berndt, U. Cvelbar** **Chair: Eva Kovacevic**	
17:15 – 17:55	S-1	**K. Koga** *Faculty of Information Sicence and ElectricalEngineering, KyushuUniversity, Japan* *Center for Novel Science Initiatives, National Institutes of Natural Sciences, Japan* Time of Flight Size Control of Nanoparticles in Reactive Plasmas
17:55 – 18:25	S-2	**J. G. Eden** *Department of Electrical and Computer Engineering, University of Illinois, Urbana, IL 61801, USA* Electromagnetic (MM-wave) and nanofabrication applications of microcavity plasmas
18:25 – 18:55	S-3	**Z. Lj. Petrović** *Institute of Physics, University of Belgrade POB 68 11080 Zemun Serbia, Serbian Academy of Sciences and Arts, Knez Mihailova 35, 11001 Belgrade, Serbia* Global Model and Diagnostics of an Atmospheric Pressure Plasma Jet in Mixtures of Helium and Water Vapour
19:15	**WELCOME DRINK &DINNER**	

Monday 16-Sept		
Chair: Johannes Berndt		
9:00 – 9:30		**R. van de Sanden** *DIFFER, P.O. Box 6336, 5600 HH Eindhoven, The Netherlands* *Department of Applied Physics, Eindhoven University of Technology, Eindhoven, The Netherlands* Recent trends in renewable energy driven chemistry for energy conversion and storage: plasma chemistry as the special case
Session M1 **NANOPARTICLES**		
9:30 – 10:00	M1-1	**H. Biederman** *Department of Macromolecular Physics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic* Low Pressure Plasma-based Formation of Heterogeneous Nanoparticles
10:00 – 10:30	M1-2	**T. Strunskus** *Chair for Multicomponent Materials, Kiel University, Germany* Application of UV light and X-rays to the analysis of nanoparticles created in a plasma
10:30 – 11:00	**coffee break & poster session**	
11:00 – 11:30	M1-3	**T. Belmonte** *Institut Jean Lamour CNRS&Université de Lorraine, Nancy, France* Metastability: the ultimate virtue of nanoparticles?
11:30 – 11:45	M1-4	**N. Krstulović** *Institute of Physics, Zagreb, Croatia* Synthesis, analysis and applications of nanoparticles prepared by laser ablation in liquids
11:45 – 12:00	M1-5	**J. Zavašnik** *Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia* In-situ TEM synthesis of NPs with ionic liquids
12:00 – 14:30	**LUNCH AND BREAK**	
Chair: Thomas Strunskus		
14:30 – 15:00	M1-6	**M. Santos** *The University of Sydney, NSW 2006, Australia* Controlled Synthesis of Nanoparticles in Dusty Plasmas for Applications in Nanomedicine
15:00 – 15:30	M1-7	**A. Choukourov** *Department of Macromolecular Physics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic* Functionalized Plasma Polymer Nanoparticles
Session M2 **PLASMAS&LIQUIDS**		
15:30 - 16:00	M2-1	**T. Ohta** *Department of Electrical and ElectronicEngineering, MeijoUniversity, Japan* Synthesis of nano-materials using gas-liquid interfacial plasma
16:00 – 16:30	**coffee break& poster session**	
Chair: Thierry Belmonte		
16:30 – 17:00	M2-2	**E. Robert** *GREMI, UMR7344 CNRS-Universitéd'Orléans, BP 6744 45067 OrléansCedex 2, France* Plasma generation using Plasma Gun above or inside liquid solutions

17:00 – 17:30	M2-3	**M. Sunkara** *Conn Center for Renewable Energy Research and Chemical Engineering, University of Louisville, Louisville, KY 40292* Plasma-molten metal and/or liquid interactions for materials processing
17:30 – 18:00	M2-4	**F. Endres** *Clausthal University of Technology Institute of Electrochemistry, ClausthalZellerfeld* Plasma Electrochemistry with Ionic Liquids
Session M3 **PLASMA CATALYSIS &MATERIAL TREATMENT** **Chair: Alexei Nefedov**		
18:00 – 18:30	M3-1	**A. Bogaerts** *Research group PLASMANT, Department of Chemistry, University of Antwerp, Universiteitsplein 1, BE-2610 Wilrijk-Antwerp, Belgium* Computer modeling for answering burning questions in plasma catalysis
18:30 – 19:00	M3-2	**S. Spirk** *Graz University of Technology, Institute of Paper-, Pulp- and FibreTechnology (IPZ), Inffeldgasse 23, 8010 Graz, Austria* Plasma treatment for cellulosic materials
19:30	**DINNER**	
Tuesday 17-Sept		
Session T **PEGASUS DAY:GRAPHENE&CARBONS** **Chair : Elena Tatarova**		
9:00 – 9:05		**E. Tatarova** Welcome to Pegasus Day
9:05 – 9:45	T-1	**M. Hori** *Center for Low-temperature Plasma Sciences, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Japan* Challenge of Plasma Nanoprocesses for Industry and Life Innovations
9:45 – 10:15	T-2	**A. Nefedov** *Institute of Functional Interfaces, KarlsruheInstitute of Technology, 76344 Eggenstein-LeopoldshafenGermany* Vertically oriented carbon nanostructures
10:15 – 10:45	T-3	**W. Bodnar** *Leibniz Institutefor Plasma Science and Technology, Felix-Hausdorff-Str. 2, 17489 Greifswald, Germany* Graphene-related carbon nanoparticles synthesized from a liquid isopropanol precursor in an one-step atmospheric plasma process
10:45 – 11:15	**coffee break& poster session**	
11:15 – 11:45	T-4	**C. Corbella** *Dept. Mechanical & Aerospace Engineering, George Washington University, DC, United States of America* Synthesis of Nanomaterials by Pulsed Anodic Arc Discharge
11:45 – 12:15	T-5	**L. Zajíčková** *CEITEC and Faculty of Science, Masaryk University, Brno, Czech Republic* Carbon Nanotubes Functional Devices Prepared by Plasma and Other Dry Gas-Phase Methods
12:15 – 14:30	**LUNCH AND BREAK**	
Chair:Uroš Cvelbar		
14:30 – 15:10	T-6	**E. Tatarova** *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*

		Microwave Plasmas Applied for Graphene Based Hybrid Nanostructures Synthesis
15:10 – 15:30	T-7	**A. Dias** *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal* Microwave plasma synthesis of graphene-metal oxides nanocomposites
15:30 – 16:00	T-8	**A. Almeida** *Centre of Physics and Engineering of Advanced Materials, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal* Structural characterization of N-graphene/Mn oxide nanocomposites synthesized by microwave plasmas
16:00 – 16:30	**coffee break& poster session**	
Chair: Nikša Krstulović		
16:30 – 17:00	T-9	**E. Valcheva** *Faculty of Physics, Sofia University, 1164, Sofia, Bulgaria* Electrical Transportin Microwave Plasma Fabricated Free-standing N-Graphene Sheets at Low Temperatures
17:00 – 17:15	T-10	**D. Tsyganov** *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049 – 001 Lisboa, Portugal* N-graphene formation applying atmospheric microwave plasma: theoretical analysis
17:15 – 17:30	T-11	**N. Bundaleska** *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049 – 001 Lisboa, Portugal* N-graphene synthesis – direct microwave plasma method
17 :30 – 18 :00	T-12	**D. Marić** *Institute of Physics, University of Belgrade, Belgrade, Serbia* Breakdown and Discharges in Low-Pressure Alcohol Vapors
18:00 – 18:30	T-13	**E. Felizardo** *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Portugal* Vacuum Ultraviolet and Extreme Ultraviolet Spectroscopy of Surface Wave Discharges
18:30 – 19:00	T-14	**J. Henriques** *Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisboa,Portugal* Vacuum Ultraviolet Radiation Emitted by Microwave Argon Plasmas
19:00	**DINNER**	
Wednesday 18-Sept		
Session W **ENERGY, DIAGNOSTIC, THRUSTERS** **Chair: J. Gary Eden**		
8:30 – 9:00	W-1	**R. Boswell** *Space Plasma Power and Propulsion Laboratory Centre for Plasmas and Fluids, RSPE Australian National University, Canberra, ACT, Australia* Quo Vadis Plasma
9:00 – 9:30	W-2	**D. Ruzic** *Center for Plasma Material Interactions, Department of Nuclear, Plasma and Radiological Engineering, University of Illinois at Urbana-Champaign, Urbana IL, 61801 USA* Femtosecond Laser Texturing at Multiple Wavelengths
9:30 – 10:00	W-3	**H. Kersten**

		Institute for Experimental and Applied Physics, Kiel University, Kiel, Germany Surface modification and nanostructuring of highly porous 3D networks by plasma treatment
10:00 – 10:30	W-4	**C. Charles** *Laboratory, ResearchSchool of Physics, TheAustralianNationalUniversity, Canberra, ACT 2601, Australia* Pocket Rocketelectrothermal plasma thruster status
10:30 – 11:00	**coffee break& poster session**	
11:00 – 11:30	W-5	**M. J. Gordon** *Dept. of Chemical Engineering, Solid State Lighting and Energy Electronics Center (SSLEEC), University of California, Santa Barbara, USA* OES imaging and Langmuir probe studies of DC and RF flow-through microplasma jet sources
11:30 – 12:00	W-6	**J. L. Walsh** *Centre for Plasma Microbiology, Department of Electrical Engineering and Electronics, University of Liverpool, L69 3GJ, United Kingdom* Turbulence and entrainment in plasma jets
12:00 -12:30	W-7	**M. Momčilović** *Institute of Nuclear Sciences Vinca, University of Belgrade,Belgrade, Serbia* Laser Induced Breakdown Spectroscopy (LIBS): An alternative approach
12:30 – 14:30	**LUNCH**	
15:00 – 23:00	**EXCURSION : Magic Istria and the truffle road** **& GALA DINNER in Rovinj**	
Thursday 19-Sept		
Session Th1 **PLASMA SURFACE INTERACTION: FROM ETCHING TO COATINGS** **Chair:Masaru Hori**		
9:00 – 9:30	Th1 – 1	**M. Vuković** *TEL Technology Center America, LLC, USA* Moore's law and the evolution of plasma etch equipment and process
9:30 – 10:00	Th1 – 2	**K. P. Giapis** *Division of Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, CA, USA* Dynamic Chemistry in Plasma-Surface Interactions
10:00 – 10:30	Th1 – 3	**J. Beckers** *Department of Applied Physics, Eindhoven University of Technology, P.O. Box 513, 5600MB Eindhoven, The Netherlands* EUV-induced plasma in nanolithography
10:30 – 11:00	**coffee break& poster session**	
11:00 – 11:30	Th1 – 4	**A. Barranco** *Consejo Superior de Investigaciones Científicas, Instituto de Ciencia de Materiales de Sevilla (CSIC-US) c/Américo Vespucio 49, Sevilla, E-41092, Spain* Encapsulation of perovskite solar cells and supported nanostructures by ultrathin plasma polymers
11:30 – 12:10	Th1 – 5	**J. G. Han** *School of Advanced Materials Science and Engineering, Center for Advanced Plasma Surface Technology (CAPST), NU-SKKU Joint Institute for Plasma Nano Materials (IPNM), Sungkyunkwan University, Suwon 440-746, South Korea* Novel design and control of thin film nucleation and growth by 3D magnetic field control in magnetron sputtering
12:10 – 14:30	**LUNCH**	

Chair: Andrey Choukourov		
14:30 – 15:00	Th1 – 6	**F. Faupel** *Chair for Multicomponent Materials, Faculty of Engineering, Kiel University, Kaiserstr. 2, 24143 Kiel, Germany* Recent advances in tailoring functional particulate and layered nanocomposites
15:00 – 15:30	Th1 – 7	**S. Radovanov** *AppliedMaterials /Varian BU, Gloucester, Massachusetts, UnitedStates of America* RF and DC sources capabilities for precision material modification and ion implantation
15:30 – 16:10	Th1 – 8	**A. Borras** *Nanotechnology on Surfaces Lab, Materials Science Institute of Seville / Consejo Superior de Investigaciones Cientificas (CSIC), Spain* One-reactor fabrication of supported 3D nanomaterials: first steps towards the all-in-one solution for the fabrication of self-powering systems and multisource energy scavengers
16:10 – 16:30	**coffee break& poster session**	
16:30 – 17:00	Th1 – 9	**J. P. Borra** *LPGP CNRS, Paris-Sud University&Paris-Saclay Univ (UMR 8578), @Centrale-Supélec, F91405 France* Plasma-based aerosol processes for composite core-shell nanoparticles and thin films: post-discharge condensation for nanoscale polymer and inorganic coatings
17:00 – 17:30	Th1-10	**A. Anselmo** *Helmholtz-Zentrum Berlin fürMaterialien und Energie GmbH, Albert-Einstein-Str. 15 12489 Berlin, Germany* CALIPSOplus – a gateway for research at light sources
Session Th2 **PLASBIOSENS SESSION: BIOLOGY&BIOSENSING** **Chair: Eva Kovacevic**		
17:30 – 18:00	Th2-1	**K. Makasheva** *LAPLACE, Université de Toulouse, CNRS, UPS, INPT, Toulouse, France* Plasma-based synthesis of multifunctional thin dielectrics: probing the interaction of silver nanoparticles with DsRed proteins
18:00 – 18:30	Th2-2	**V. Shvalya** *Jožef Stefan Institute, Ljubljana SI-1000,Slovenia, EU* Exploring Performance of Highly Robust Au/Pd Plasmonic Substrates for Biosensing with SERS
18:30 – 19:00	Th2-3	**K. Takahashi** *Faculty of Electrical Engineering and Electronics, KyotoInstitute of Technology, Japan* Bio-applications of water mist in plasmas as a form of dusty plasmas
19:00 – 19:30	Special Talk	**K. Ken Ostrikov** *Convenor – iPlasmaNano conference series* *Queensland University of Technology (QUT) and CSIRO-QUT Joint Sustainable Processes and Devices Laboratory Brisbane, QLD 4000, Australia* Clean future: what can plasma do for you?
19:30	**DINNER**	
Friday 20-Sept		
Session F **Chair: Zoran Lj. Petrović**		
9:00 – 9:30	F-1	**D. Pai**

		Institut Pprime (CNRS UPR 3346 – Université de Poitiers – ISAE-ENSMA), 11 boulevard Marie et Pierre Curie, F-86962 Futuroscope Chasseneuil, France In-situ OES and Raman spectroscopy related to nanostructuration by atmospheric-pressure plasmas
9:30 – 9:45	F-2	**M. Košiček** *Jožef Stefan Institute, Jožef Stefan International Postgraduate School, Ljubljana, Slovenia* Phase transformations in copper oxide nanowires
9:45 – 10:00	F-3	**M. Rakić** *Institute of physics, Zagreb, Croatia; University of Illinois at Urbana-Champaign, USA* Laser resonators with nanoparticles gain medium for new laser profiles and optical logic gates
10:00 – 10:30	**coffee break**	
10:30 – 11:00	F-4	**S. Dujko** *Institute of Physics, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia* Electron transport in C_2H_x gases (x = 2, 4 and 6) in DC and RF fields
11:00-11:30	F-5	**M. Mičetić** Ruđer Bošković Institute, Zagreb, Croatia Preparation and basic properties of Ge quantum dot lattices in amorphous Al_2O_3, Si_3N_4 and SiC matrices
11:30	**CLOSING CEREMONY**	

POSTERS

Zoran Ereš

Institute Ruder Boskovic

Graphene production and application

Gregor Filipič

Institute Jozef Stefan

Metal-oxide sensor geometry consideration on a case study of copper-oxide nanoflake sensor deposited by atmospheric plasma

Andrea Jagodar

GREMI UMR 7344, CNRS&University of Orleans, 14 rue d'Issoudun, 45067 Orléans Cedex 2, France

PANI film on carbon nanowalls: synthesis and analysis

Martina Modic

Laboratory for Gaseous Electronics, "Jožef Stefan" Institute, Jamova cesta 39, Ljubljana, Slovenia

Department of Electrical Engineering and Electronics, University of Liverpool, Brownlow Hill, Liverpool L69 3GJ, United Kingdom

Atmospheric Pressure Air Plasma Sources for Orthopaedic Biofilm Decontamination

Boris Okorn

Institute Ruder Boskovic

Rotating nanoparticles with optical forces –nanotechnology with a twist

Dario Sciacqua

GREMI UMR 7344, CNRS&University of Orleans, 14 rue d'Issoudun, 45067 Orléans Cedex 2, France

Study of polymerization process in a capacitively coupled discharge operating in aniline argon mixture

Eric von Wahl

GREMI UMR 7344, CNRS&University of Orleans, 14 rue d'Issoudun, 45067 Orléans Cedex 2, France

Plasma assisted synthesis of carbon nanowalls and nanotubes

Andreja Šestan

Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia

Influence of He implantation and post-annealing on microstructure in tungsten matrix composites

Oral Abstracts

Structural characterization of N-graphene/Mn oxide nanocomposites synthesized by microwave plasmas

A. Almeida[1], L. Silva[1], A. Dias[2], N. Bundaleska[2], J. Zavasnik[3], U. Cvelbar[3], A. M. Ferraria[4], A.M. Botelho do Rego[4], J. Henriques[2], E. Tatarova[2]

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[4] *CQFM-Centro de Química-Física Molecular and IN and IBB-Institute for Bioengineering and Biosciences, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal)*

This work reports on the characterization of free-standing N-graphene/MnO nanocomposites synthesized by atmospheric pressure sustained microwave plasmas in a single-step using carbon/nitrogen gas precursors, injected in the hot plasma region, and MnO_2 particles injected in the mild plasma region. The samples were structurally, chemically and morphologically characterized by XRD, SEM, HRTEM, Raman and XPS.

Free-standing N-graphene sheets containing a relatively homogeneous dispersion of MnO nanoparticles have been successfully produced in a single-step. The material is formed of single- to few-layer N-graphene sheets with a doping level of 3.8%N, mostly in pyridinic- and pyrrolic bonding configurations, and MnO nanoparticles. The nanoparticles are mostly MnO, with an estimated average size of ~30 nm, though the presence of a small fraction of α-Mn_3O_4 nanoparticles with sizes under 10 nm is also detected. The results show that a reduction of the MnO_2 particles to MnO has occurred during composite synthesis.

Acknowledgments

The work is being developed under the EU H2020-FETOPEN-1-2016-2017 Project PEGASUS, contract 766894 and Fundação para a Ciência e Tecnologia, Project EAGER, PTDC/NAN-MAT/30565/2017.

CALIPSOplus – a gateway for research at light sources

A. Anselmo[1], A. Vollmer[1], B. Seidlhofer[1], B. Schramm[2], M. Grobosch[2], M. Helm[2]

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[2] *Helmholtz-Zentrum Dresden-Rossendorf e.V., Bautzner Landstrasse 400, 01328 Dresden, Germany*

The Trans-national Access programme of CALIPSOplus (Convenient Access to Light Sources Open to Innovation, Science and to the World) provides supported access of European researchers to European and Middle Eastern light sources [1]. This project is funded by the European Commission within the EU Framework Programme for Research and Innovation H2020.

Particular attention is given to leveraging scientific excellence across the EU and to widening the use of light sources throughout the region. A **Twinning programme** has been set up aiming at establishing and further developing new scientific communities, particularly from countries without own light source [2]. Potential users are partnered with host groups that share their know-how and expertise in applying the available experimental techniques to common research areas. Scientists new to synchrotron-based techniques have the opportunity to participate in a fully-financed hands-on introduction to the facilities.

References

[1] http://www.calipsoplus.eu/calipsoplus-in-a-nutshell/

[2] https://www.helmholtz-berlin.de/user/user-info/eu-support-programmes/

Encapsulation of perovskite solar cells and supported nanostructures by ultrathin plasma polymers

F.J. Aparicio[1], J. R. Sanchez-Valencia[1], J. Idígoras[2], L. Contreras[2], J.A. Anta[2], K. Ostrikov[3], A. Borrás[1], A. Barranco[1]

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Remote plasma assisted vacuum deposition (RPAVD) is a very versatile methodology for the synthesis of functional films and multilayers for photonic, sensing, nanoelectronic and biomedical applications. Besides, the RPAVD methodology permits to deposit highly conformal multifunctional organic films to encapsulate fragile supported nanostructures without affecting their molecular structure and atomic bonding. In this work, we use this plasma enabled nanoencapsulation approach to improve the stability of perovskite solar cells under water and moisture exposure. The deposition of the polymer is carried out at room temperature by the remote plasma vacuum deposition of adamantane powder. This encapsulation method does not affect the photovoltaic performance of the tested devices and is virtually compatible with any device configuration independent of the chemical composition. After 30 days under ambient conditions with a relative humidity (RH) in the range of 35-60%, the absorbance of encapsulated perovskite films remains practically unaltered. The deterioration in the photovoltaic performance of the corresponding encapsulated devices also becomes significantly delayed with respect to devices without encapsulation when vented continuously with

very humid air (RH > 85%). Besides the encapsulation is robust enough to let measure the power conversion efficiency of encapsulated devices under operation in water. The proposed method opens up a new promising strategy to develop stable photovoltaic and photocatalytic perovskite devices.

EUV-induced plasma in nanolithography

J. Beckers[1], T.H.M. van de Ven[2], R.M. van der Horst[2], and V.Y. Banine[1,2]

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[2] *ASML The Netherlands B.V., P.O. Box 324, 5500AH Veldhoven, The Netherlands*

One peculiarity in nanolithography is the inevitable presence of plasma induced by the interaction of the used high energy (92 eV) extreme ultraviolet (EUV) photons with the low pressure hydrogen background gas. While being initiated in the volume of such rarefied gas, this plasma and the connected dynamics may impact the processes at optical surfaces and construction materials. In this contribution we highlight our joint experimental endeavours to understand and predict this plasma's behaviour.

Acknowledgments

This work was financially supported by ASML

Metastability: the ultimate virtue of nanoparticles?

N. Tarasenka,[1] A. Nominé,[2] A. Nevar,[1] M. Nedelko,[1] H. Kabbara,[3] S. Bruyère,[3] J. Ghanbaja,[3] C. Noel,[3] A. Krasilin,[2, 4] G. Zograf,[2] V. Milichko,[2] N. Kulachenkov,[2] S. Makarov,[2] N. Tarasenko[1] and T. Belmonte,[3].

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[4]*Ioffe Institute, St. Petersburg, Russia*

On the way that joins equilibrium to instability, one intermediate leg is metastability. This specific state of matter benefits from a substantial singularity while being robust enough to withstand non-equilibrium conditions for a sufficiently-long period of time. Beyond the obvious case of human-beings, one finds also nanoparticles, a funny playground to break the rules obedient to the devilish minimum of energy.

Three ways are very trend nowadays to synthesise nanoparticles with such an arrogant behaviour: two-chamber sputtering, laser ablation and pulsed discharges in liquids. They all have pros and cons that will be evoked in this lecture. The main advantage that these processes offer is their ability to quench a given state at extremely high rate, a key condition to achieve metastability. This condition is further

accompanied by two other secondary effects: surface functionalization and defect control. The former is often dealt with by chemical treatments. The latter is mastered only in rare cases and always for nanoparticles at equilibrium, as far as we are aware of it. Both effects can also be coupled, like in the case of oxidation, where the outward diffusion of one metal to form a passive oxide layer leaves behind charged vacancies.

We will finish by examples of what is sought after and some new achievements made in this field. The example of Cu-Ag is quite outstanding and demonstrates that miscibility becomes possible even though the corresponding phase diagram claims the opposite. But metastability is not only a matter of composition, it can also be a matter of shape or allotropy. The example of □-PbO_2 will be given, showing the possible synthesis of a new phase under the shape foils thanks to these processes far from equilibrium.

Low Pressure Plasma-based Formation of Heterogeneous Nanoparticles

A.Shelemin[1], J. Hanuš[1], M. Cieslar[2], P. Solař[1], A. Kuzminova[1], P. Kúš[3], O. Kylián[1],

A. Choukourov[1], H. Biederman[1]

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The preparation of nanoparticles by gas aggregation using low pressure plasma is introduced with special attention paid to planar magnetron-based gas aggregation cluster sources (GAS) of a Haberland type. The main emphasis is given to the investigation of the possibility to employ GAS systems for the production of multi-component, heterogeneous metal-metal or metal-plasma polymer nanoparticles and their thorough characterization. Several strategies are described such as the use of composite target, utilization of multiple magnetrons in one aggregation chamber, or sequential (in-flight) coating of the NPs using different planar and cylindrical magnetron geometries. It is shown that NPs with core@shell or multi-core@shell structures may be produced depending on the operational conditions. Future development and possible applications are outlined.

Acknowledgments

The study was supported by the grant 17-22016S from the Czech Science Foundation and by the grant LTC17062 from the Ministry of Education, Youth and Sports of the Czech Republic.

Graphene-related carbon nanoparticles synthesized from a liquid isopropanol precursor in an one-step atmospheric plasma process

W. Bodnar[1], M. Schiorlin[1], A. Frank[2], T. Schulz[1], C. Scheu[2], J. Kolb[1],

A. Kruth[1]

[1] *Leibniz Institute for Plasma Science and Technology, Felix-Hausdorff-Str. 2, 17489 Greifswald, Germany*

[2] *Max Planck Institute for Iron Research GmbH, Max-Planck-Str. 1, 40237 Düsseldorf, Germany*

The cost-efficient production of graphene for electronic and electrochemical applications at an industrial scale is still a big challenge demanding for the development of novel manufacturing methods. A promising and environmentally friendly single-step-approach is the plasma-in-liquid method. A reactor was built in-house and short bipolar pulsed electric discharges were generated directly in isopropanol creating nanographite structures. The influence of pulse width, repetition frequency, and processing time on the product was systematically investigated. Long pulses promote the creation of amorphous and oxidic carbon structures. Although, hydrocarbon cracking and subsequent graphitization do occur, these process conditions are not suitable to drive the reduction processes. In contrast, applying short pulses and high repetition frequencies results in higher energy density of the plasma in liquid and therefore ensures fast reduction processes and formation of graphene-related nanostructures.

Acknowledgments

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Computer modeling for answering burning questions in plasma catalysis

Annemie Bogaerts, Yannick Engelmann, Koen Van Laer,
Weizong Wang, Quan-Zhi Zhang and Yu-Ru Zhang

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Plasma catalysis is gaining increasing interest for various environmental applications, but the underlying mechanisms are not yet fully understood. The catalyst (and packing materials) will affect the plasma behavior, while the plasma will also affect the catalytic reactions. In this talk, I will present examples of both (physical and chemical) effects, based on computer modeling. First, I will show the electric field enhancement near the contact points of packing beads in a packed bed DBD reactor, yielding higher electron temperature, which can explain the higher performance of a packed bed reactor compared to an empty DBD reactor [1]. I will also present streamer propagation through the packing beads, based on both fluid modeling and particle-in-cell Monte Carlo simulations [2]. Furthermore, I will demonstrate plasma propagation and plasma enhancement inside catalyst pores, for various pore sizes, and explain the underlying mechanisms [3-5]. Finally, I will also present modeling results of the

plasma chemistry, including surface reactions at the catalyst surface, to predict the role of the catalyst in plasma-assisted NH_3 formation.

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Plasma-based aerosol processes for composite core-shell nanoparticles and thin films:

post-discharge condensation for nanoscale polymer and inorganic coatings

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Plasmas are used for long as coating process by PE-CVD i.e. by condensation of vapours produced by reactions of gaseous precursor *injected in the plasma*. Coatings are also achieved from liquid precursors droplets converted into polymer grafted on surface in the gap[1, 2] and ref. Badyal in [3].

"Softer" post-plasma processes will be addressed for tuneable thickness functional polymer or thermostable SiOx coatings of films and suspended NanoParticles (NP). Such post-DBD (Dielectric Barrier Discharge) condensation occurs when saturation of gaseous species is reached by cooling of vapours for chemistry-free coating or by reactions of plasma species with liquid[4]/gaseous[5] precursors.

At first for coatings by non-reactive condensation, plasma filaments in DBD produce NP, mixed with hot vapours downstream the plasma. Condensation arises by cooling vapours. Coating thickness is tuned with relative densities of vapour and NP, for calibrated aerosol generators (d_{mod}€ [2; 100] nm) [3].

Post-DBD reactive coating processes are used to preserve the monomer functionality ie to achieve functional coating properties with large surface density of organic moieties or the thermostable properties of SiO_x coating on agglomerated NP to keep large exchange surface for interfacial process at high temperature[5]. Avoiding electrode coating, the discharge leads to quasi-stationary post-DBD flux of active species in gas or on surface. Coating thickness is then tuned by precursor amount and reaction duration:

- Polymerization of organic liquid precursor→ grafted functional polymer (anti-fouling) coatings[4],

- Reactive condensation (PE-CVD) of gaseous metal-organic precursor→ thermostable NP@SiO_x[5].

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One-reactor fabrication of supported 3D nanomaterials: first steps towards the all-in-one solution for the fabrication of self-powering systems and multisource energy scavengers

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In this communication we will share our last advances in the development of multifunctional 1D and 3D supported nanostructures into the fields of solar cells,[1,2] micro-energy harvesting (piezoelectric and triboelectric nanogenerators)[3] and photoelectrocatalysis. The advantages of the soft-template procedure based on the use of single crystal organic nanowires as 1D templates and the plasma-vacuum one-reactor approach will be presented and analysed. Special emphasis will be put in the introduction of micro-energy harvesting context and the potential role of 1D and 3D nanomaterials multisource energy harvesting. Advances in the field of nano-magnetism[4] and development of semitransparent nanoelectrodes and slippery liquid infused surfaces[5] will be also introduced.

Acknowledgments

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Quo Vadis Plasma

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Research in gaseous plasma physics can be considered to have commenced in the mid 1950s with the British toroidal pinch experiment ZETA producing neutrons. This discovery and its optimistic explanation resulted in the first major embarrassment for fusion physics when it was discovered that the fast neutrons came not from fusion reactions but from plasma instabilities. Mark Oliphant, who had first measured fusion cross section in 1934, came to the newly established Australian National University and started a plasma physics group in 1958. It was here that the first "Tokomak" in the west was constructed in the mid 1960s. And so for the next 60 years fusion physics has promised clean cheap energy just over the horizon, an ephemera that has kept thousands of physicists off the streets chasing the bright elusive butterfly of elusive success.

In the mid 1970s, it was shown that dry etching of silicon based semiconductors could be achieved by using plasmas to generate reactive radicals. This is now one of the most important strategic industries in the world as all microelectronic devices are fabricated using plasma etching and deposition, an industry worth trillions of dollars. This talk will present a personal view of someone who has been involved with and contributed to the industry since the early 1980s.

N-graphene synthesis – direct microwave plasma method

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Selective synthesis of N-graphene (nitrogen-doped graphene) using direct microwave plasma method at atmospheric pressure conditions was achieved. The method involves introduction of carbon and nitrogen precursors (ethanol and ammonia) into the active argon plasma environment, where they decompose into simpler "building" species, such as C, C_2, N, HCN etc [1, 2, 3]. Tailoring the plasma properties, i.e. microwave power, gas flow rates and mixtures, substrate-free N-graphene sheets were synthesised with doping level of 1.5 at % N. Such synthesis can only be achieved in a narrow range of operational parameters [3]. The structural quality of the produced structures was analysed by

Scanning Electron microscopy, Transmission Electron microscopy and Raman spectroscopy. X-ray photoelectron spectroscopy revealed the relative extension of the graphene sheets π-system and the type of nitrogen chemical bonds present in the lattice structure.

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Pocket Rocket electrothermal plasma thruster status

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Progress in satellite technologies is ongoing and eventually finds applications back on Earth. Electric propulsion (EP) has been an innovative or complementary solution in a number of space missions but its scalability remains a challenge especially when considering standardised satellite platforms such as CubeSats. The Pocket Rocket electrothermal radio frequency plasma thruster has now reached Technology Readiness Level 7 and uses a compact, efficient and less expensive power supply with pulsed operation and "instant on" capabilities developed as a joint effort between groups at the Australian National University and Stanford University. Prototyping optimisation and testing based on the availability of new material and components continues with progress on performance results being released in publications; this provides the sector with a scientific open access baseline. Initial testing on satellite bus interface is underway.

Synthesis of Nanomaterials by Pulsed Anodic Arc Discharge

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Atmospheric arc discharge with periodic anode ablation shows better performance in nanomaterial synthesis compared to steady DC arc discharge [1]. The main advantages of pulsed arc performance comprise improved process control, arc stability, potential in material properties tailoring, and growth of high-quality materials thanks to lower production of macroparticles. Pulsed arc syntheses of low-dimensional carbon (graphene, nanotubes) and molybdenum disulfide nanomaterials are treated as examples for this new deposition method. Plasma parameters and electrical properties of pulsed arc discharge are characterized and related to basic plasma structure. Structural and morphological analysis of the cathode deposit shows high concentration of carbon nanoparticles. Finally, a global model based on total pressure evolution provides a scenario for the observed erosion dynamics and optical emission patterns associated to the different arc discharge phases.

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Microwave plasma synthesis of graphene-metal oxides nanocomposites

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In the present work, an atmospheric pressure microwave plasma-based method [1] is used to synthesize free-standing N-doped graphene (NG) and NG metal oxides composites (NGMO's). In order to produce N-graphene sheets a methane-methylamine gas mixture is injected into a surface wave sustained argon plasma with an applied power of 2 kW. Moreover, in order to produce the NGMO's metal oxide micron size particles are injected in the reactor. Subsequently, the NGMO's are wrapped with a polymer using a capacitively coupled RF plasma polymerization method [2] at low pressure conditions. The samples were characterized by transmission and scanning electron microscopy, Raman spectroscopy, X-ray photoelectron spectroscopy, near edge X-ray absorption fine structure spectroscopy, X-Ray diffraction and by contact angle technique.

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Electron transport in C_2H_x gases (x = 2, 4 and 6) in DC and RF fields

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In this work, we investigate the electron transport in C_2H_x gases (x = 2, 4, and 6) in DC and RF electric and magnetic fields. In DC electric fields, transport coefficients are measured with a scanning drift tube apparatus [1] over a broad range of E/N, 1Td ≤ E/N ≤ 1790 Td, where 1 Td = 10^{-21} Vm^2. Measurements are compared to the results of previous experimental studies, as well as to the solutions of the Boltzmann equation and Monte Carlo simulations [2]. Measurements and calculations of transport coefficients in C_2H_x gases (x = 2, 4 and 6) are augmented by considering the electron transport in various N_2-CH_4 mixtures. These transport coefficients and cross sections for electron scattering in N_2 and CH_4 are then used as an input in fluid models and PIC/MC (particle in cell/Monte Carlo) simulations to study the propagation of streamers with the aim of investigating the possibility for the occurrence of lightning in the atmosphere of Titan [3].

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ELECTROMAGNETIC (MM-WAVE) AND NANOFABRICATION APPLICATIONS OF MICROCAVITY PLASMAS

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Plasma photonic crystals (PPCs) operating in the 120-300 GHz (mm-wave) region have been realized with three-dimensional (3D), periodic arrays of 355 μm diameter plasma columns. Interspersed with metal and/or dielectric microcolumns in a woodpile or cubic, "super 3D" configuration, these microplasma arrays constitute an artificial material with electromagnetic functionality. Specifically, these PPCs exhibit multiple attenuation resonances that blue-shift with increasing electron density, and line-profile Q values above 10,000 have been observed. Microplasma-assisted atomic layer deposition (MALD) of Al_2O_3 and Ga_2O_3 has also been demonstrated. With a 50 × 20 array of microplasmas situated in proximity to a Si wafer, 15-185 nm thick Al_2O_3 films have been grown at a rate of 2.25 A/growth cycle. Ga_2O_3 films grown by MALD yield high quality, solar-blind photodetectors. Finally, a photoresist-free photolithography at 172 nm has been demonstrated and will be described.

Plasma Electrochemistry with Ionic Liquids

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Ionic Liquids usually have that low vapor pressures that they can be handled under the conditions of an Ultrahigh Vacuum, e.g. enabling XPS measurements even under electrochemical control. Due to

their outstanding chemical and electrochemical stability they are suited to the electrochemical synthesis of elements and compounds that cannot be made in aqueous and in most cases also not in organic solutions. Examples are Si, Ge, Ga-Ti, Ta and others. The low vapor pressure of ionic liquids allows experiments under the condition of a low temperature low pressure plasma. In the case of an Argon plasma electrons are accelerated to the surface of the liquid, where at the interface IL/plasma a reduction occurs, e.g. creating metal and semiconductor nanoparticles. Furthermore carbon nanotubes can by this method be decorated with metal nanoparticles. The lecture will give an overview on this research field and show some recent results.

Recent advances in tailoring functional particulate and layered nanocomposites

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Nanocomposite films consisting of metallic and dielectric building blocks have unique functional properties with hosts of applications. Particulate nanocomposites are mostly made up of metallic nanoparticles embedded in a polymer or a ceramic matrix with a high filling factor close to the percolation threshold. Here control of the particle separation on the nm scale is essential because the functional properties often require short-range interaction between nanoparticles. The Kiel group employs vapor phase deposition, which is a scalable approach and allows excellent control of the metallic filling factor, its depth profile as well as the incorporation of alloy nanoparticles with well-defined composition. Recently, we focus on *in situ* control and monitoring of nanoparticle formation in gas aggregation cluster sources [1]. This includes formation of core-shell particles, e.g. Al nanoparticles with defined oxide shell for UV plasmonics [2]. Concerning the matrix, initiated chemical vapor deposition (iCVD) turned out to be a versatile technique for the deposition of polymer films without destruction of the functional groups [3]. Examples of recent work in Kiel are memristive and memsensor devices for neuromorphic electronics [4], photocatalytic coatings with different combinations of wide-bandgap semiconductors and nanoparticles [2], as well as novel sensors for gases and volatile organic compounds, involving semiconductors and core-shell nanoparticles [5]. Moreover, we will show a new process for photocatalytic growth of Au nanostructures [6]. In addition to the particulate composites, new results on layered magnetoelectric composites will be presented, extending our earlier concept (Appl. Phys. Lett. 99 (2011) 223502; Research Highlight, Nature 480 (2011) 155. for robust, fully integrable, broadband magnetic field sensors based on the delta E effect). This includes a sensor based on guided surface acoustic waves (Love waves) [7] and a novel energy efficient magnetic field sensor incorporating an organic electret layer [8].

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Vacuum Ultraviolet and Extreme Ultraviolet Spectroscopy of Surface Wave Discharges

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VUV emissions of Ar and H_2 discharges and the EUV emission of Helium discharges are investigated using a VUV/EUV Plane Grating Monochromator coupled to a 2.45 GHz waveguide-surfatron plasma source at low pressure (0.1-2 mbar). The spectra of Ar discharges comprises atomic and ionic emissions with the most intense spectral lines corresponding to the atomic resonance lines, at 104.8 nm and 106.7 nm, and to the ion lines, at 92.0 nm and 93.2 nm. Also recorded were lines for which no information concerning level transitions exists in the NIST database (e.g. 89.4 nm) [1,2]. Strong emissions of Lyman H_2 ($B^1\Sigma_u^+$- $X^1\Sigma_g^+$) and Werner H_2 ($C^1\Pi_u$-$X^1\Sigma_g^+$) molecular bands along with Lyman-α and Lyman-β atomic lines at 121.6 nm and 102.6 were detected in H_2 containing discharges [1]. In He, spectral lines corresponding to singly ionized helium atoms in the 20 – 32 nm wavelength range were measured [3]. The variations of the emission intensities with applied power and working pressure are analysed.

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Dynamic Chemistry in Plasma-Surface Interactions

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Ions exiting the plasma sheath possess kinetic energy which can cause "Chemical Sputtering", that is, material removal from exposed surfaces at rates much larger than those expected from physical sputtering. When the ion energy is low (10-300 eV), energetic ions can themselves participate in dynamic chemistry, independent of surface temperature. The talk will focus on two classes of such reactions involving molecular ions: 1) the Eley-Rideal-type abstraction of surface adsorbates, and 2) the intra-molecular rearrangement of the constituent atoms that leads to unexpected dissociation products. The reactions are demonstrated by water ion scattering experiments, where molecular oxygen is produced on oxidized surfaces[1] and molecular hydrogen is released on generic surfaces.[2] While these specific examples find applications in astrophysics, the reaction types are generally applicable to plasmas and offer a remarkable platform to access reaction pathways previously thought impossible, such as the direct conversion of CO_2 to O_2 in single collisions.[3]

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OES imaging and Langmuir probe studies of DC and RF flow-through microplasma jet sources

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Spatially-resolved OES imaging and double Langmuir probe (DLP) measurements were carried out on DC and RF flow-through supersonic microplasma jets to highlight how plasma operating conditions (e.g., pressure, current, presence of growth precursors/O_2, distance from the nozzle) affect the local gas (T_{rot} and T_{trans}) and electron (T_e) temperatures in the plasma jet plume. T_{rot} and T_{vib} were estimated using semi-emperical and rigorous quantum mechanical fits to OES spectra of the first positive group of N_2 ($B^3\Pi \rightarrow A^3\Sigma_u^+$), and T_e was obtained via fits to DLP IV curves. Experiments on DC Ar jets with downstream pressures in the 10-200 Torr regime yielded estimates of $T_{rot} = T_g$ and T_{vib} of 500-700 K and 5000-6000 K, respectively, using two independent methods. DLP data gave estimates of T_e in the 1-3 eV range, which depended on the exact location in the expanding jet plume. The transition between a pre-discharge-like operating regime at low plasma currents and true hollow cathode operation at high currents was also observed in the DC plasma IV characteristic and companion OES measurements. The talk will highlight OES imaging and DLP results for low pressure DC and atmospheric pressure RF microplasma jets.

Novel design and control of thin film nucleation and growth by 3D magnetic field control in magnetron sputtering

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The control of magnetic field intensity and configuration in magnetron source is a key factor for control of plasma discharge and thin film structure closely associated with film nucleation and growth. The film nucleation and growth is mainly controlled by flux density and energy of sputtered particles with process temperature, typically substrate temperature. In addition, the collision of sputtered particles during deposition makes a change of film density and surface morphology.

The new trend of thin film synthesis required in digital electronics and optoelectronic industry is reduction of film thickness and damage with crystalline structure at very low temperature less than 100C. However, it is well known that crystalline structure synthesis of most oxides films at low temperature cannot be achieved by conventional magnetron sputtering due to limited energy flux for crystallization.

Therefore we have made new design and control of film process with novel magnetron sputtering. The magnetic field was confined to 3 dimensional hollow type configuration with additional rectangular side wall mode on planar magnetic configuration. The discharge behaviour and plasma parameters of 3D magnetron sputtering source were compared with those of conventional planar magnetron sputtering source. The discharge characteristics and corresponding particles deposition behaviour were observed to be significantly changed. The noted change is formation of nano clusters

in sputtered particles in 3D magnetron sputtering. The crystalline film was then successfully synthesized for sputtering of ITO(Indium Tin Oxide) at low substrate temperature less than 100 C

In this presentation, the design concept of 3D magnetic field confinement and resulting discharge behaviour is discussed in comparison with those of conventional planar magnetron sputtering source.

The formation mechanism with control of nucleation and growth is discussed for crystalline ITO film formation at low temperature by 3D magnetic controlled sputtering.

Acknowledgments

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Vacuum Ultraviolet Radiation Emitted by Microwave Argon Plasmas

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An experimental and theoretical investigation of a microwave Argon plasma vacuum ultraviolet (VUV) light source operating at low-pressure conditions is presented. The plasma source was studied using visible and VUV optical spectroscopy, the electron density, the relative VUV emission intensities of the atomic resonance lines and ions were studied as a function of the microwave power delivered to the launcher. Experimental results were analyzed using a 2D self-consistent theoretical model [1-3] based on a set of couple equations including the electron Boltzmann equation, the rate balance equations for the most important electron excited species and charged particles, the gas thermal balance equation, and the wave electrodynamics. The main population and loss mechanisms considered in the model for the excited argon atom and ion states emitting in the VUV range are discussed. The experimental results were compared to self-consistent model predictions, and a good agreement was obtained.

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Challenge of Plasma Nanoprocesses for Industry and Life Innovations

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Low-temperature plasma interactions among multiple phases (e.g., ambient air, liquids, and cell-membranes) give rise to various phenomena such as electrical discharge phenomena at the boundaries with microscopically viewable constituents. In this article, we present our recent studies in regard with the synthesis of carbon nanomaterials of two-dimensional nano-graphene (Carbon Nanowalls) employing low temperature plasmas[1-2)]. Such nanocarbons exhibit excellent characteristics of fuel cell devices[3)]. Additionally, organic materials were etched by precisely controlling of the species and the substrate temperature. Eventually, the pattern of organic thin film below 10nm size was fabricated with a novel self-limit processing[4)]. The interaction of plasma with liquid enables to synthesis of the plasma activated liquid, which causes selectively killing cancer cells against normal cells[5)]. We will discuss plasma nanosciences among multiple phases indispensable for the sustainable future society.

Acknowledgments

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Surface modification and nanostructuring of highly porous 3D networks by plasma treatment

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Tetrapodal ZnO (T-ZnO) and aerographite networks represent two highly open porous model materials on which the impact of an atmospheric-pressure plasma was studied for the first time [1].

The air plasma treatment by a diffuse coplanar surface barrier discharge (DCSBD) caused remarkable surface modifications on the T-ZnO template, leading to a large number of oxygen vacancies. These observations were made using scanning electron microscopy (SEM) and Raman spectroscopy. The DCSBD plasma was studied by several diagnostics, in particular, by calorimetric probes to determine the energy influx during plasma treatment[2].

In the second proposed set-up, pellets of aerographite material were processed to a plasma jet with pressurized air and nitrogen. Hexamethyldisiloxane (HMDSO) was introduced as a precursor into the effluent of the jet for nanoparticle deposition. Opposing trends in atomic concentrations versus distance to the plasma source were observed when the gas (nitrogen or pressurized air) was changed. More pronounced

nanoparticle coverage occurred in the pressurized air plasma. Again, their distribution was studied using SEM, energy-dispersive X-ray (EDX), and Raman spectroscopy. Because of the higher oxidation in the pressurized air plasma treatment, the deposited nanostructures appeared to be a mixture of Si and Si*O*x nanoparticles.

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Time of Flight Size Control of Nanoparticles in Reactive Plasmas

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We have developed a continuous nanoparticle synthesis method of reactive plasmas with fast gas flow. For the method, particle generation region and their deposition region are divided. The nanoparticles are nucleated and grow in discharges. They are transported by the fast gas flow in the hollows and then their growth is stopped outside the hollows. They are transported toward the substrate placed in the downstream region. Using the method, we have succeeded in continuously synthesizing Si nanoparticles of 2 nm in mean size with 0.5 nm in size dispersion [1-5]. In this study, we employed the $Ar+CH_4$ plasma for synthesizing carbon nanoparticles to discuss growth mechanism of the nanoparticles. To realize the fast gas flow, we employed a multi-hollow discharge plasma chemical vapor deposition method which can realize a short gas residence time of a few ms. The nanoparticles are nucleated in the discharge and transported by the fast gas flow. During the transport, they are grown in the discharge and the growth is stopped outside of the plasma. Here we discuss the effects of their time of flight in the plasma on their growth.

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Phase transformations in copper oxide nanowires

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In recent years our group has been extensively studying the growth of copper oxide nanowires achieved by thermal and plasma-assisted methods. Due to their semiconducting properties, copper oxide nanowires have great potential in the semiconducting industry. Their potential usage covers wide areas of possible applications, such as in solar energy harvesting, water splitting, gas sensing etc.
In our present study, we studied the influence of different parameters such as temperature and pressure on the growth of copper oxide nanowires and were able to obtain ultra-thin nanowires with diameters of approximately 10 nm. Characterisation of nanowires was carried out with Raman spectroscopy and electron microscopy methods (SEM and TEM). Furthermore, copper oxide nanowires were exposed to hydrogen sulphide (H_2S) gas at atmospheric pressure and room temperature for two hours. Changes in nanowires were studied with Raman spectroscopy, X-ray photoelectron spectroscopy (XPS) and electron microscopy techniques. Results show that upon H_2S exposure copper oxide nanowires transform into polycrystalline chalcocite (Cu_2S) nanostructures. Different stages of conversion were found: some nanowires were completely converted to sulfide, and on the others, residuals of oxide core were found in the centre, indicating the possible mechanism of conversion. The fact that copper oxide nanowires can undergo such transformations at ambient conditions shows their potential applications in H_2S sensing and catalysis as agents for hydrodesulfurization of the fossil fuels. Further studies on the subject may also unravel a way to convert single-crystal copper oxide nanowires into copper sulfide

nanowires, which are harder to obtain than metal oxide nanowires but hold useful properties, such as high solar energy conversion incase of Cu_2S.

Synthesis, analysis and applications of nanoparticles prepared by laser ablation in liquids

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Laser synthesized colloidal solutins of TiO_2, ZnO, Au and Ag nanoparticles has been used for incorporation into different materials with atmospheric pressure plasma jet (APPJ) and for applications in photocatalysis. Laser synthesis of nanoparticles is based on a process of laser ablation of metallic targets in liquids [1]. By laser ablation in liquids a synthesis of nanoparticles from wide variety of materials (metals, semiconductors, alloys, glass) is possible which makes it as versatile synthesis technique [2,3]. It is known as 'green' synthesis method because there are no chemicals involved in the synthesis and chemical reaction byproducts which is the main advantage of this method over the standard chemical methods where often additional purification is needed [4]. Treatment and incorporation of nanoparticles into materials such as PVC polymers by atmospheric pressure plasma jet (APPJ) will be discussed [5,6]. Photocatalytic activity on different dyes of ZnO and TiO_2 nanoparticles has been studied. One of the topic of this talk is development and verification of a quantitative method for determination of concentration of nanoparticles synthesized by laser ablation in liquids.

Acknowledgments

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Plasma-based synthesis of multifunctional thin dielectrics: probing the interaction of silver nanoparticles with DsRed proteins

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Current strategies for development of new biomaterials take into consideration the fundamental "protein adsorption problem" and the associated protein structure/function relationship because of the exposure of proteins to non-biological solid surfaces. Plasma-based processes successfully apply to the synthesis of biomaterials. However, their rational engineering requires knowledge on the plasma behavior in order to design the structural, optical, electrical and bio-related properties of the deposits.

In this work we exploit the multifunctionality of silver nanoparticles (AgNPs) as plasmonic antenna when embedded in thin SiO_2 layers (called plasmonic substrates) and as biocide agents because of their strong toxicity towards micro-organisms [1]. We propose an appropriate strategy to study the 'protein-adsorption problem' and to probe the interaction of AgNPs with proteins through coupling of AgNPs and *Discosoma* red fluorescent proteins (DsRed) that display exceptional photo-stability [2-4].

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Breakdown and Discharges in Low-Pressure Alcohol Vapors

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Discharges involving alcohols, weather in a liquid phase, gaseous phase or at their interface, are found to be advantageous in nanotechnologies, for the fast growth of graphene layers and nanotubes [1]; in the fuel industry, in hydrogen production and in fuel reforming [2]; and many other fields. Our work is motivated by the key challenges in transport, chemistry, reaction rates and cross sections relevant for such discharges. We present measurements of electrical and emission properties of discharges in vapours of methanol, ethanol, isopropanol and n-butanol in the range of *pd* (pressure x electrode gap) from 0.06 Torr cm to 2 Torr cm, covering the region of Paschen minimum [3]. Space, time and spectrally resolved emission profiles of the discharges reveal kinetics of electrons, ions, and fast

neutrals. Furthermore, recorded emission profiles enable determination of effective ionization coefficients and secondary electron yields [3] for the *E/N* (electric field/gas number density) range 1 kTd–5 kTd. The measured data provide information on elementary processes and identification of relevant species, which represents a basis for modelling of plasmas in alcohol vapours.

Acknowledgments

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Laser Induced Breakdown Spectroscopy (LIBS): An alternative approach

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We will present laboratory LIBS setup developed in our research group. The proposed LIBS setup differs from the commonly practiced LIBS systems in two respects, applied the infrared TEA CO_2 laser as the excitation source and time integrated spatially resolved (TISR) signal detection. This original LIBS system is of lower complexity and cost compared to standard LIBS systems. In ours previous works, we already reported that plasma produced by irradiation of a TEA CO_2 laser related to Nd:YAG laser has comparable capabilities for spectrochemical analysis of different types of samples.

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Vertically oriented carbon nanostructures

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The presentation is devoted to vertically oriented carbon nanostructures. The methods of their preparation, characterization and possible applications will be discussed. A few examples of such nanostructures will be demonstrated. These nanostructures will also be compared with other classes of carbon nanostructures.

Synthesis of nano-materials using gas-liquid interfacial plasma

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A gas-liquid interfacial (GLI) plasma is an atmospheric pressure plasma generated between the electrodes in the gas phase and in the liquid phase. In this study, Copper nanoparticles (CuNPs) have been synthesized using the GLI plasma without a toxic reducing agent. In this study, alternative - current (AC) power source was used so that electrons, ionic species and reactive species were supplied to liquid phase. The reduction behaviour of CuNPs was determined by pH and oxidation-reduction potential of the liquid solution by the plasma treatment. The effects of non-toxic reducing auxiliary agent and capping agent on the characteristics of CuNPs were investigated.

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Clean future: what can plasma do for you?

Kostya (Ken) Ostrikov

Convenor – iPlasmaNano conference series

Queensland University of Technology (QUT) and CSIRO-QUT Joint Sustainable

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This presentation discusses some of the key features of low-temperature plasmas that make it versatile tool in materials science and engineering and other areas such as chemical engineering and health sciences – this making them of particular interest for the development of future industries including clean energy industries and other clean technologies of the future. Key attention is paid on synergistic effects of plasmas with common materials and processing methods and what difference it makes in diverse applications, with particular focus where nanoscale features of materials play a role.

These localized interactions have opened opportunities for fundamental research and applications in the plasma nanoscience field. The focused "what can plasma do for you" examples will be used to stimulate

collaborative efforts even between researchers normally working in very different fields of research.

In-situ OES and Raman spectroscopy related to nanostructuration by atmospheric-pressure plasmas

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We apply in situ Raman microspectroscopy and spatially-resolved optical emission microspectroscopy to the study of the interactions of liquids and surfaces in contact with atmospheric plasmas. Such interactions are studied in the context of two experiments related to nanomaterials synthesis. First, the generation of a nanosecond pulsed surface dielectric barrier discharge on a silicon wafer results in its nanostructuration in open ambient air at atmospheric pressure. Second, graphene quantum dots are synthesized in aqueous solution using a microplasma electrochemical reactor.

Acknowledgments

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Global Model and Diagnostics of an Atmospheric Pressure Plasma Jet in Mixtures of Helium and Water Vapour

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Detailed spatially resolved modelling of plasmas usually requires kinetic or may be performed by hybrid kinetic/fluid models. Using such models it is beyond current capabilities to include hundreds of different species that contribute to the rich, plasma-induced chemistry so for that purpose 0D global models are being used. The most complex systems that are being studied presently are atmospheric pressure plasma jets where initial helium flow is often mixed with some water vapour and/or oxygen and then upon generation of plasma it is mixed with the external air that may have its own humidity. We have found excellent agreement between our simulations [1] for the flow of 3 slm of He with 7600 ppm of water mixed with 1% of air and the mass spectrometry measurements at 23 mm from the end of the APPJ glass tube [2]. Our results are also consistent with those for measured OH densities [3] and for electron densities and dependence of rates on humidity from [4].

Acknowledgments

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RF and DC sources capabilities for precision material modification and ion implantation

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In recent years, a development of large area radio frequency RF sources enabled plasma doping and precision material modification at very high ion current density [1,2]. For example, a dynamic random-access memory application requires incredibly high doses ~$5x10^{16}$ /cm^2 that can be done by plasma doping systems. Unlike the DC beam line implanters, ions are not mass analysed, but instead the wafer is processed in an adjacent vacuum chamber. The plasma is generated by an inductively coupled RF coil and the wafer is pulsed negatively by a bias supply with a square wave at f~1-50 kHz. Ion energy is controlled by the bias voltage which can exceed 10 kV. When bias is on a plasma sheath forms in front of the wafer surface, across which ions are accelerated into the target. The ion angular distribution modulation in Ar, H_2 and O_2 plasmas is studied here. We also discuss fluid plasma models, electrostatic and space charge simulations associated with DC and RF systems.

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LASER RESONATORS WITH NANOPARTICLES GAIN MEDIUM FOR NEW LASER PROFILES AND OPTICAL LOGIC GATES

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I will present experimental setup for generation of new laser profiles which are fully defined inside the resonator. That means that they to do not require any additional optical shaping and presents a challenging task for use in particle confinement, laser tweezers, magneto-optical and gravito-optical traps, optoelectronics and in communication technology. Specifically, I will show realizations of linear and cylindrical laser profiles. Experimental setup is made up of laser resonator consisting of two mirrors, gain medium CdSe nanoparticles in solution, and an additional optical component placed within the resonator that is responsible for the shape of the output laser profile. This optical component proved to be the most challenging part of the setup since it had to be almost completely transparent in order to achieve a laser effect. For pump beam we used a 532 nm from nanosecond YAG laser and achieve the output laser emission at 655 nm (which is defined with used CdSe nanoparticles). Additionally, we used similar setup to achieve a NOT logical gate, which due to the

use of the nanoparticles in solution and not the standard semiconductor elements, present a unique realization of completely optical logic gate.

Plasma generation using Plasma Gun above or inside liquid solutions

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Low temperature plasma treated solutions are under intense study with respect to their key importance for plasma biomedical, plasma environmental and plasma agriculture technologies applications [1,2]. In this work, we report on the use of various plasma jet based delivery protocols likely to generate reactive species enriched solutions for such applications. The baseline setup consists in the use of the Plasma Gun (PG) device [3] delivering a so called plasma plume a few mm away from the liquid to be treated. Such single jet configuration is easily turned into a multi jets setup [4], using a branching capillary assembly, while keeping the same power supply operated with the same voltage amplitude and microsecond pulse repetition rate together with the same range of buffer gas flow rates flushed inside the primary capillary plasma generation reactor. As a second kind of protocol, we report on the liquid solution treatment when plasma reactor capillary is immersed inside liquid solutions, thus resulting in the generation of plasma inside buffer gas bubbles. Reactive species generation in liquid solutions is reported using either plasma plumes or in-bubble plasmas based on the Plasma Gun devices. In-bubble plasma generation with triggering of plasma ignition at different stages of the bubble dynamics, offers opportunities for reactive species balance modulation. Our experiments show that plasma can be delivered in small volume bubbles which then allow for efficient diffusion in the bulk liquid solution, thus opening opportunities for efficient high repetition rate multi bubbles plasma delivery.

Acknowledgments

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Femtosecond Laser Texturing at Multiple Wavelengths

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Femtosecond laser have been demonstrated to produce periodical self-organized nanostructures known as laser induced periodical surface structures (LIPSS). These ripples are due to the recondensation of metal plasmas at the target surface in a non-equilibrium state. The orientation of the ripples are dependent on the instantaneous electric field which is a result of the laser light being linearly polarized.

To date, a variety of tunable parameters have been demonstrated to affect ripple features. Power and laser spot repetitions affect the depth of the fringes, but not their spacing. Spacing, combined with feature depth, are the two most important physical (non-chemical) determinations of hydrophobicity on the surface via the Cassie-Baxter wettability theory. Presented here will be the effects of light wavelength on ripple spacing offering an additional tool to surface texturing and manipulation.

Recent trends in renewable energy driven chemistry for energy conversion and storage: plasma chemistry as the special case

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In a circular CO_2 neutral society, where the use of dense energy carriers based on carbon will still be needed, the re-use of (air captured) carbon dioxide is required. These dense energy carriers can be utilized to mitigate intermittency of renewable energy sources by providing seasonal storage, as feedstock for the chemical industry to replace fossil based feedstock and as green fuels for long haul and air transport. The use of electrons, from renewable electricity, or photons, directly from the sun, provide scientific and technological opportunities to develop novel pathways for chemical conversion. In this talk, after an introduction to the challenges facing the world in the next decades, I will discuss the opportunities of using plasmas, powered by renewable electricity, for scalable gas conversion of key molecules such as CO_2 and N_2. In particular I will address the use of microwave plasma to dissociate CO_2 into CO and O_2, and the possible role of nonequilibrium vibrational kinetics. Also a novel plasma enhanced membrane reactor for the production of H_2 and NO will be discussed.

Controlled Synthesis of Nanoparticles in Dusty Plasmas for Applications in Nanomedicine

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Translation of nanocarriers into the clinic has been limited by time-consuming and expensive synthesis and post-functionalization protocols, requiring linker chemistry to tether molecules into a single, multifunctional nanostructure. Here, we show that controlled synthesis of carbon-based plasma polymerized nanoparticles (PPN) in acetylene-based dusty plasmas [1], often regarded an undesirable by-product in many applications, can robustly bind multiple classes of molecules in a fast and cost-effective process [2], enabling delivery of a wide range of therapeutics. Functional groups formed in the plasma bulk are spontaneously incorporated and preserved onto PPN during synthesis, facilitating a robust immobilization of biomolecules. Comprehensive in-vitro and in-vivo experiments show that PPN are safe at concentrations well above their therapeutic dose and significantly improve the persistence, bioavailability and activity of molecules delivered to the vasculature and tumours.

Acknowledgments

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Functionalized Plasma Polymer Nanoparticles

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Plasma-based approaches are considered here for the synthesis of polymer nanoparticles (NPs) enriched with specific functional groups. Plasma polymerization of volatile precursors (*n*-hexane, acrylic acid, hexamethyldisyloxane) and rf magnetron sputtering of polymer targets (teflon, nylon) are

employed to produce N-, COOH-, CF_2- or SiO_2 functionalized NPs. Embedding of these NPs into matrices of counter-polymers is also presented. Potential applications of the resultant structures are highlighted that include, but not limited to, the control of the surface wetting and binding of biomolecules.

Acknowledgments

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Exploring Performance of Highly Robust Au/Pd Plasmonic Substrates for Biosensing with SERS

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Reusable plasmonic substrates are crucial for the development of biosensing applications using surface-enhanced Raman scattering (SERS), as they can provide unique advantages for ultrafast and accurate single-molecule recognition of different species. In this research, we employed thermally annealed cupric CuO and cuprous oxide Cu2O heterostructures to serve as highly stable nanotextured surfaces for designing robust 3D plasmonic biochips.

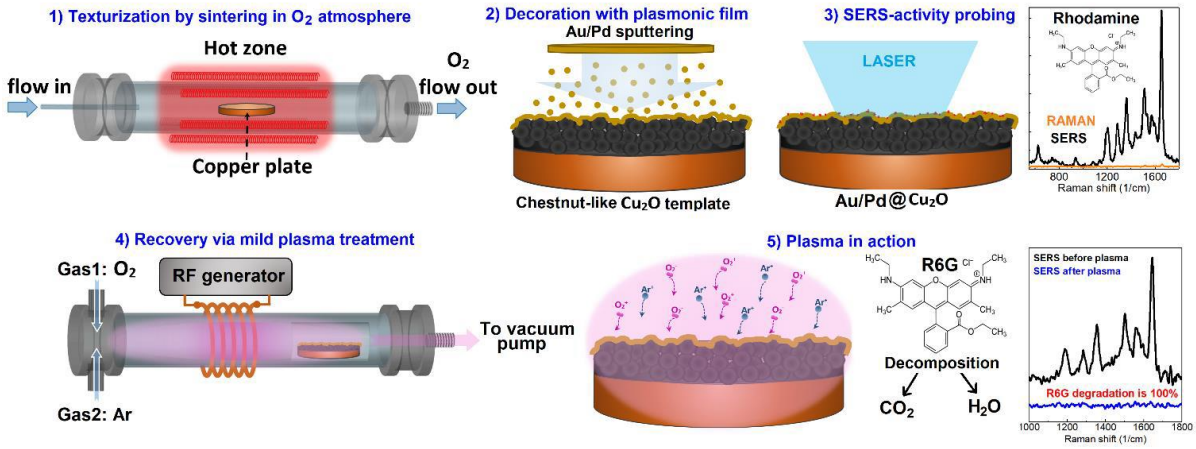

Figure 1: Schematic representation of a research outline. *Step 1* – controllable surface texturing by thermal annealing at oxygen-enriched atmosphere. *Step 2* – plasmonic activation by ion spattering of Au/Pd alloy film. *Step 3* – SERS performance monitoring by means of R6G dye fingerprint detection. *Step 4* – Recovery test under ultra-fast mild cleaning in reactive oxygen/argon plasma. *Step 5* – Simplified scheme of Rhodamine degradation inside plasma followed by the vanishing of the characteristic peaks in the Raman spectrum.

The influence of bimetallic layer thickness on SERS performance has been studied for the chestnut patterned substrate. **Figure 2 F** depicts Raman spectra of Rhodamine used as a model biomarker (600-1800 cm-1) complemented by a signal originated from the Cu2O layers (100-800 cm-1).

During Au/Pd film thickness reduction from 80 nm down to 20 nm, the R6G peak intensities undergo a gradual decrease, simultaneously, acoustic bands originated from Cu2O nanoparticles located in a range of 100-800 cm-1 become dominant. In accordance with **Figure 2 G**, that displays a signal intensity dropping for in-plane C-H bending vibrations as a function of bimetallic layer thicknesses, the analytical enhancement factor AEF acquires the following values: for 60 nm ~ 9.8×104, for 40 nm ~ 8.4×104 and for 20 nm ~ 1.1×104, respectively. The analogous finding was observed for Au decorated CuO nanoflakes, where EF increases with a noble metal film thickening [1].

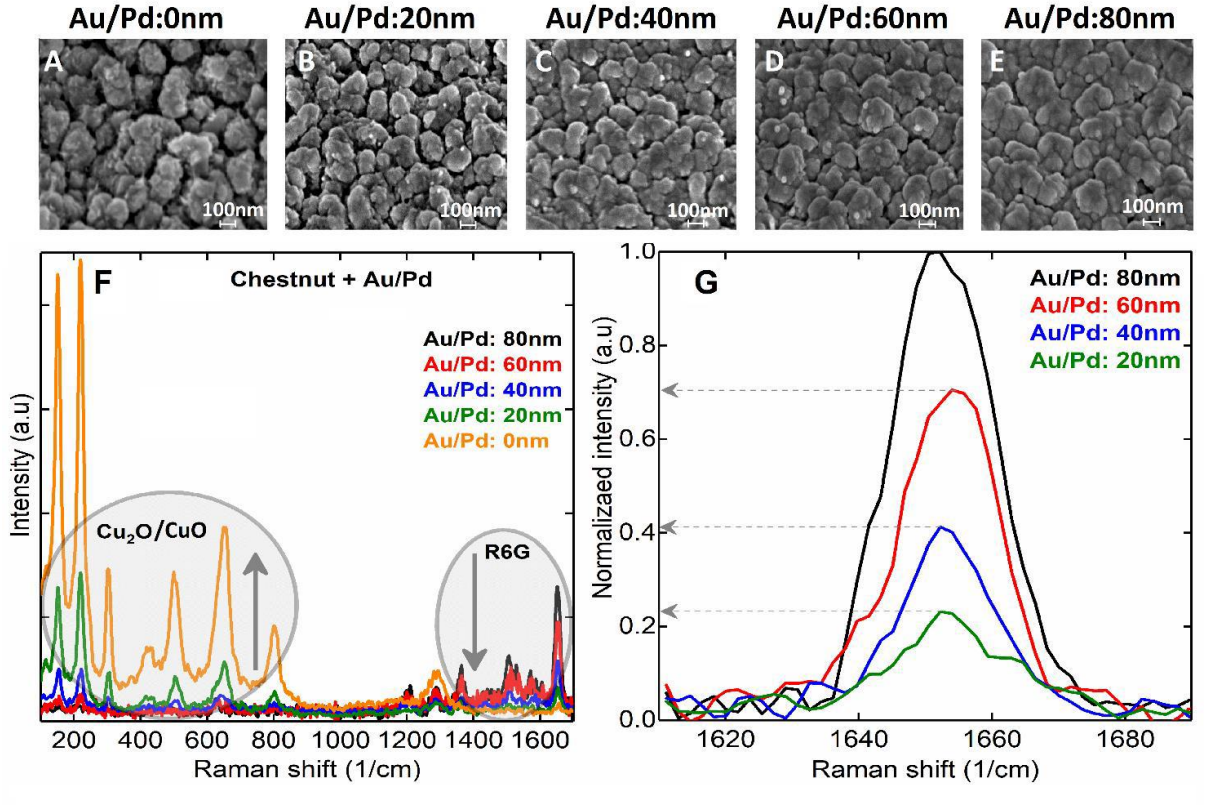

Figure 2: (A-E) – SEM images showing the cuprous oxide Cu2O surface morphology altering with Au/Pd alloy thickening. (F) – Broadband Raman spectra representing vibrational features of chestnut Cu2O structures decorated by different plasmonic thicknesses together with ethanol diluted Rhodamine 10-5 M absorbed on the surface. (G) – Normalized intensity of the in-plane C-H bending vibrations of R6G 10-5 M as a function of bimetallic film thickness.

Due to prominent anti-reflection properties, CuO/Cu2O heterostructures [2] appear to be an extremely suitable material for designing SERS-active substrates. Moreover, the high chemical inertness of Au/Pd alloy plasmonic layer allows a non-destructive substrate recovery with the assistance of reactive plasma species. Furthermore, the generation of reactive oxygen species-rich plasma by introducing oxygen gas into argon plasma drastically reduces cleaning session to less than 1 minute. For our best knowledge, this is the shortest recovery time for any 3D plasmonic SERS substrate reported in the literature. Additionally, results indicate that the nano-roughness is more important for achieving optimal plasmonic activity than micro-roughness. Overall, the designed chestnut-like Au/Pd@/Cu2O substrate is a ready-to-use chip that possesses a decent signal enhancement ~ 105 and reveals remarkable robustness under multiple plasma treatment showing nearly 100% of self-recovery with no degradation of a plasmonic layer. These findings are of great significance for the development

of novel reliable SERS substrates with low-cost manufacture which can be utilised with great success in a wide area of plasmonic biosensing.

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Plasma treatment for cellulosic materials

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Plasma treatment of cellulosic materials can be used to modify their surface properties, in particular surface free energy. After a short overview on plasma modifications of cellulose we focus on different aspects how to modify cellulosic materials using plasma. A focus is given on thin films, where hydrophobic cellulose derivatives can be converted to hydrophilic cellulose using oxygen plasma treatment. However, degradation reactions take place (particularly peeling), which are dependent on the exposure time and partial pressure of the oxygen plasma.

The second approach for functionalization of cellulosic substrates involves nanoparticles. In particular, we used fines, a micro and nanostructured fibrous form of cellulose, which was impregnated with nanoparticle suspensions which were obtained by laser assisted synthesis from metal precursors.[1] As a proof of concept we could demonstrate that the materials impregnated with AgNPs did not leach from the paper substrates and exhibited good antimicrobial activity.

Acknowledgments

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fund. NK acknowledge the COST Action TD 1208 for fruitful discussions. E. coli K12 was donated by Laboratory for Biology and Microbial Genetics, Faculty of Food Technology and Biotechnology, University of Zagreb (Zagreb, Croatia).

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Application of UV light and X-rays to the analysis of nanoparticles created in a plasma

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In this talk I will report on two cases how light can be applied in the analysis of plasma created nanoparticles. First, I report on the in-situ investigation of the initial stages of metallic NP growth in a low temperature plasma by broadband transmission UV-Vis spectroscopy. We demonstrate that for several metals due to strong particle plasmon resonance, small clusters and NPs can be monitored by UV-Vis spectroscopy in-situ during their growth and transport in a gas aggregation cluster source. We Observe that small clusters are already generated in the region close to the magnetron target surface and generally do not change their size much during transport through the gas aggregation volume. Our measurements indicate that a high concentration of nanoparticles is located near the magnetron.

Secondly, I will report how near edge x-ray absorption fine structure spectroscopy (NEXAFS) can be used to analyse the nitrogen doping of different carbonaceous structures obtained from a plasma and how it can be applied as a tool to help to identify the different nitrogen species.

Acknowledgments

Special thanks go to our cooperation partners,i.e. the group of H. Biedermann and A. Choukorov, Prague University and to E. Kovacevic from University of Orleans. Funding by German science foundation through project B13 of TR24 and project A2 of RU2093 is gratefully acknowledged, as well as funding by EU through the project PEGASUS.

Plasma-molten metal and/or liquid interactions for materials processing

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Plasma based materials processing has been shown to be promising for combinatorial techniques and scalable processing. For example, our group has shown that gentle plasma excitation of gas phase will allow the use of non-catalytic, low melting metals for catalyzing nanowire growth. Furthermore, the use of plasma oxidation of liquid precursors allowed for creation of metastable complex oxide particles with compositional control. A number of examples will be discussed in which the above two techniques are currently being used for developing III-V and complex oxides for energy conversion and storage applications.

This talk will highlight our efforts to understand the role of plasmas under two categories: (a) the synergistic effects hydrogen and nitrogen plasma interactions with molten metals; and (b) the oxygen plasma-liquid droplet interactions. To gain insights into these mechanisms we have studied the interaction of hydrogen and nitrogen plasmas with low melting point metals, primarily with gallium. Experiments have shown an increment of adsorbed gaseous species into the molten metal in the presence of plasmas. In the case of oxygen plasma-liquid droplet interactions for creating complex oxides, the role of solvated electrons, oxygen radicals and heating effects will be discussed. Finally, the use of plasmas for achieving liquid phase epitaxial growth of GaN and related materials will be discussed.

Acknowledgements

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Bio-applications of water mist in plasmas as a form of dusty plasmas

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Bio-applications of plasmas have attracted the interest of researchers for a decade. Especially, the plasma sterilization, where plasmas are most likely generated at atmospheric pressure and exposed to bacteria on surfaces, has been focused attention on as an alternative of methods with ethylene oxide gas, high-pressure steam, ultra-violet lump and so on. This presentation shows that an atmospheric pressure plasma including water mist has a performance to kill bacteria [1]. We discuss effects of the

mist on sterilization and possibilities of the “misty plasmas” to open new applications for a form of dusty plasmas.

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Microwave Plasmas Applied for Graphene Based Hybrid Nanostructures Synthesis

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One of the greatest challenges in the commercialization of graphene and derivatives is production of high quality material in bulk quantities at low price and in a reproducible manner. The very limited control, or even lack of, over the synthesis process is one of the main problems of conventional approaches. Herein, we present a microwave plasma-enabled scalable routes for continuous, large-scale fabrication of free-standing graphene based hybrid nanostructures. The method’s crucial advantage relies on harnessing unique plasma mechanisms to control the material and energy fluxes of the main building units at the atomic scale [1]. By synergistic tailoring of the high energy density plasma environment and thermodynamic conditions in the assembly zone of the plasma reactor a controllable synthesis of high quality graphene based hybrid nanostructures was achieved.

Acknowledgments
The work was performed under auspices of PEGASUS (Plasma Enabled and Graphene Allowed Synthesis of Unique nano Structures) project. The project has received funding from European Union's Horizon research and innovation programme under grant agreement no. 766894. Work was also partially funded through Eager project (PTDC/NAN-MAT/30565/2017).

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N-graphene formation applying atmospheric microwave plasma: theoretical analysis

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In this work, theoretical studies of fundamental physical issues associated with plasma driven, controlled self-organization of free-standing N-graphene nanosheets in a plasma medium are presented. The system under theoretical analysis consists of a microwave argon plasma operating at

2.45 GHz at atmospheric pressure in a cylindrical plasma reactor with an expanding radius. Considering C_2H_5OH/NH_3 as carbon/nitrogen precursors the free-standing N-graphene formation is described in the framework of two approaches. The first approach involves the so-called equilibrium concept, i.e. minimization of Gibbs energy of the system under consideration. The second approach is based on a set of nonlinear spatially dependent differential equations describing plasma thermodynamics and chemical kinetics. The contribution of the main "building blocks" to N-graphene formation is illuminated. The theoretical findings are validated with experimental results.

Acknowledgements. This work was performed under the framework of the Plasma Enabled and Graphene Allowed Synthesis of Unique nano-Structures, funded by the European Union's Horizon research and innovation programme under grant agreement No 766894.

Electrical Transport in Microwave Plasma Fabricated Free-standing N-Graphene Sheets at Low Temperatures

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Electrical conductivity of high quality free-standing graphene and N-graphene (nitrogen doped graphene) sheets produced via microwave-driven plasmas at atmospheric pressure is investigated. The graphene sheets are compressed in tablets and arrangement upon compaction is observed the sheets being pronouncedly parallel to the tablet plane. The current flow mechanism is explored measuring longitudinal electrical conductivity and specific resistivity at temperatures from 300 K down to 10K. The resistivity increases with decreasing temperature (i.e. $d\rho/dT < 0$) opposite to the typical metallic behavior. Moreover, the measured characteristics show nonmonotonicity revealing change of the slope at a certain temperature indicating competing physical processes in different temperature ranges. The charge transport exhibits a transition between thermally activated behavior at higher temperatures and variable range hopping at lower temperatures.

Acknowledgments
This work was performed under the framework of the PEGASUS (Plasma Enabled and Graphene Allowed Synthesis of Unique Nanostructures) project, funded by the European Union's Horizon research and innovation program under grant agreement No. 766894.

Moore's law and the evolution of plasma etch equipment and process

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Driven by economic pressures which manifest themselves as Moore's law, over the past 35-40 years the transistor gate length has shrunk by a factor of 100 (from 3 microns to 30 nm), wafer size has increased by a factor of 4 (from 75 to 300 mm), the gate stack materials have changed (SiO_2 to HfO_x

gate) and geometry have changed as well (from planar to tri-gate). At the same time, the number of yielding transistors on a chip has gone from 30,000 into billions of billions.

How has the plasma etch chamber, chemistry, parameters, control changed during this time span to help produce billions of identical and functioning on a chip? And what do we expect of plasma etch equipment and process when transistor dimensional scaling stops, and we start stacking transistors vertically?

As a test case, this presentation will explore the evolution of the transistor gate and the gate etch equipment and process: how etch tools, chemistry, process uniformity and variability requirements, process control have evolved to faithfully etch billions of features to yield a functioning chip.

Turbulence and entrainment in plasma jets

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Low temperature atmospheric pressure plasma jets generate a highly reactive and targeted stream of chemical species that have found application in a number of materials processing and healthcare applications. Understanding the complex interactions between the discharge and the downstream gas is the key to understanding and potentially controlling how reactive species are produced and transported to a downstream sample. Recently, several studies have indicated that electrohydrodynamic forces generated by the plasma are able to influence the downstream flow field acting to enhance entrainment of ambient air into the discharge region [1,2].

In this investigation particle imaging velocimetry (PIV) and laser induced fluoresce (LIF) were used to provide quantitative insights into the complex fluid interactions downstream of the orifice in a helium plasma jet. By capturing the velocity profile of both the flowing and background gas the impact of plasma generation on the flow structure was identified. LIF was used to demonstrate that entrainment of air into the laminar region of the jet flow is also enhanced due to plasma generation, resulting in a significant increase in OH radical production. Ultimately, it was shown that plasma induced shear layer perturbations were the dominant mechanism of air entrainment in the laminar region of the plasma jet.

Acknowledgments

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Carbon Nanotubes Functional Devices Prepared by Plasma and Other Dry Gas-Phase Methods

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Due to their attractive properties, carbon nanotube (CNTs) have been already proposed for many applications. The present work will discuss the fabrication of functional devices for two different purposes: (i) welding-free manipulation of the micro-objects under high vacuum conditions in the electron microscopes and (ii) chemiresistive gas sensing. Both these applications are based on the high surface-to-volume ratio of the CNTs forest prepared by catalytic chemical vapor deposition (CCVD). The former needs to solve the problem of the CNTs growth on different materials, and therefore, we will discuss the growth, i.e., the efficiency of the catalyst, on various materials. The application will be demonstrated by attaching a sample chunk to a micro-manipulator (e.g., EasyLift), as well as by mounting the chunk onto a half-moon transmission electron microscope (TEM) grid. The later application often requires surface modification of the CNTs to improve the analyte adsorption and create heterojunctions. In this work, we also investigated the modification of CNTs by plasma enhanced CVD (PECVD) and atomic layer deposition (ALD). The application will be demonstrated by the performance of the ammonia gas sensor.

In-situ TEM synthesis of NPs with ionic liquids

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The observation of the liquids and gases in TEM by high-energy electrons (typically 200-300 kV) will significantly affect the observed sample, and in most cases cannot be avoided. As for the case of conventional samples, decreasing the acceleration voltage can significantly mitigate the radiation damage (mainly knock-on displacement of atoms within a crystalline region). In liquids and gases, each inelastic collision produces excited species, and the radiolysis will in fact increase at lower voltages, latter presenting a main obstacle for successful in-situ reproduction of chemical reactions inside electron microscope. In the presentation, some of the fundamentals, limitations and novel approaches in the liquid-flow in-situ synthesis and characterization of the nanomaterials by TEM will be presented, together with recent advances on the example of modified synthesis of anisotropic gold nanoparticles, and contribution of the electron beam on the chemistry of the chemical reactions.

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Poster Abstracts

Metal-oxide sensor geometry consideration on a case study of copper-oxide nanoflake sensor deposited by atmospheric plasma

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Metal-oxide gas sensors are very simple chemical sensors, especially when operated in ohmic regime. However, despite their simplicity, they are still not completely understood. Even the basic sensing mechanism in the simplest model presume complicated oxygen involvement into entrapment of holes in the depletion layer of the sensor surface, which get released when exposed to reducing gas, which removes the oxygen.[1] In this work we used this simple model for Barsan to study the ohmic response of copper-oxide nanoflakes to exposure to different amines. The sensor was deposited in the form of 2D nano-flake array on copper intercalated electrodes using atmospheric plasma source.[2,3] The sensor was inserted into electrical furnace and heated to 373 K. Then amines were injected with 70 g/h rate and the resistive response was measured. Sensor was investigated before and after the sensing experiments with SEM, TEM and XPS. It was observed that copper oxide flakes are copper I oxide single crystalline covered with very thin copper II oxide as they are deposited. However, after the measurements of sensor response, the material was transformed into thin nanorods of copper I oxide covered with relatively thick mixture of copper II oxide and amine contribution. Despite the morphism, the sensor activity was only mildly affected. We have expanded (simplified) Barsans model to consider very thin samples and shown, that the geometry of the sensor does not influence the sensor response as long as at least 1 dimension is shorter than the materials Debye length.

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Analysis of carbon nanowalls obtained by PECVD

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The interest in novel, often carbonaceous materials with large effective surfaces, high conductivity, stability, is growing due to the downsizing of electrical devices and the demand for low-cost new materials.

These demonstrate many potential applications such as electrochemical devices, storage materials for gas, transistors and biosensors.

In this work the synthesis and analysis of CNWs and graphene nanocomposites synthesis, such as Polyaniline (PANI) – CNWs composites, will be presented. Possible application of CNWs and PANI-CNWs nanocomposites is in carbon based microelectronic parts of biosensors. CNWs are produced by low temperature plasma procedures, supported by prior annealing within the same system. The plasma properties during annealing, growth process and polymer deposition were chosen in order to obtain the best conditions and minimum material damage. The material structure, e.g. morphological, chemical and microstructural features, is revealed by employing near edge X-ray absorption fine structure (NEXAFS) spectroscopy, in combination with X-ray photoelectron spectroscopy (XPS), on the HE-SGM beamline at the synchrotron radiation facility BESSY II in Berlin (Germany). NEXAFS is a unique method to obtain information on the surface states (bonding states, fingerprint of materials).

Acknowledgments

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Atmospheric Pressure Air Plasma Sources for Orthopaedic Biofilm Decontamination

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Biofilms are microbial communities colonising surfaces and embedded in a matrix composed of exopolysaccharides together with proteins and excreted nucleic acids. Biofilms are ubiquitous and they can impact all aspects in our life. Biofilms occurring in the natural environment are mostly composed of mixed bacterial species, organised in complex microcolonies. Due to this architecture and organisation biofilms offer numerous advantages over unprotected planktonic cells, providing protection against immune system defence and the diffusion of antibiotics. Conventional methods to control bacteria by chemical, physical and biological ways are usually inefficient in the case of biofilms. For this reason, there is an urgent need to establish new strategies for the inactivation of

established biofilms. Cold atmospheric pressure plasma is an emerging technology that is currently under intense investigation for microbial decontamination applications. In this contribution we focused on the comparison of the efficacy of two widely used atmospheric pressure air plasma configurations to inactivate mixed species biofilms; *i.e.* a direct plasma jet system and an in-direct plasma surface barrier discharge (SBD) system. The antimicrobial effect of the SBD is attributed to longer lived plasma generated species, such as O_3 and NO. Conversely, in the direct system, bacteria in the biofilm are exposed to both short lived species, such as O and OH in addition to long lived species, electric fields and UV photons. Single and mixed-species biofilms composed of *Escherichia coli* and *Staphylococcus epidermidis* were used as models in the study. It was observed that both plasma systems, direct and non-direct, were capable of achieving a significant level of decontamination of the biofilm contamination. Critically, the small contact area of the plasma plume in the jet system was found to be a distinct disadvantage; requiring the sample to be continually moved through the discharge in order to achieve a significant level of inactivation. The indirect plasma treatment was found to be highly effective even at short exposure times; given that many of the highly reactive neutral species produced in the plasma region are not transported to the sample surface it is proposed that the inactivation effect observed is driven by large densities of long-lived neutral species.

Study of polymerization process in a capacitively coupled discharge operating in aniline argon mixture

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Plasma enhanced chemical vapour deposition (PECVD) is a technique that originates from the conventional chemical vapour deposition (CVD). PECVD is a technique that allows in particular the deposition of ultra-thin and pinhole free polymer films on a great class of substrates. The main role of cold plasmas in this kind of processes is to dissociate the monomer at lower temperatures compared to classical CVD, without completely destroying it. The species formed in this way are subsequently used for the deposition of thin films or under some circumstance for the production of nanoparticles [1].

This contribution will deal with the study of polymerization process in capacitively coupled discharge operating in aniline argon mixture. In this context, the contribution will mainly focus on the role of positive ions and different kind of radicals on the properties of plasma polymerized thin films. For this purpose, different kinds of electrode designs will be used to separate the influence of different species.

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Influence of He implantation and post-annealing on microstructure in tungsten matrix composites

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Helium (He) retention in material can importantly affect the mechanical and structural properties, such as tensile strength, creep and fatigue behaviour or swelling [1]. Materials swelling is induced by He agglomeration after post-annealing in form of He-bubbles formation [2]. Retention of He influences not only the material properties but also the transport and retention of hydrogen isotopes (HI), both deteriorating the overall performance of the materials [3,4].

Like all engineering materials, also tungsten contains certain levels of impurities, which have additional impact on high-temperature stability [5]. In our research, addition of refractory carbide was used to refine grain boundaries and prevent the oxide phase growth [6].

The sintered samples were implanted with high-energy He ions and annealed at high temperature. After both steps the samples were characterized using electron microscopy.

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Plasma assisted synthesis of carbon nanowalls and nanotubes

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The outstanding mechanical, electrical and thermal properties of carbon nanomaterials make them attractive for present and future applications [1], like solar cells [2] and electronic devices [3], where the ever increasing performance meets new technical challenges in terms of power delivery, heat removal and thermomechanical reliability. The nanostructures can vary in shape from spheres to flakes, vertical walls and to tubes. Many of them exhibit a graphene-like atomic structure with a high content of sp2-hybridization.

In this work the synthesis of carbon nanotubes and carbon nanowalls will be presented. It was achieved by plasma enhanced chemical vapor deposition (PECVD) at substrate temperatures from 450°C to 650°C. The process conditions (reactor design, choice of materials, catalyst pre-treatment, gas composition, substrate temperature) and their influence will be discussed accompanied by results from SEM, XPS and NEXAFS.

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