24th SYMPOSIUM

PLASMA PHYSICS & RADIATION TECHNOLOGY

CENTRUM
VOOR PLASMAFYSICA EN
STRALINGSTECHNOLOGIE

Dutch Physical Society
Section Plasma and Gas Discharge Physics
&
Research school
Center for Plasma Physics and Radiation Technology

Nederlandse Natuurkundige Vereniging

March 6 & 7 / 2012 CongresHotel De Werelt - Lunteren

This symposium is organized by the board of the section plasma- and gas discharge physics of the Netherlands' Physical Society in close collaboration with the research school 'Center for Plasma Physics and Radiation Technology'

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Programme & Abstracts

March 6 and March 7 / 2012
CongresHotel De Werelt
Lunteren

General Information

Address

The address of the CongresHotel De Werelt is: Westhofflaan 2, 6741 KH Lunteren.Telephone: 0318-484641, e-mail: info@dewerelt.nl
The route to the conference center is signposted in Lunteren.
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If you have any questions about the conference, please contact: Rina Boom, telephone: 040-2472550, e-mail: k.c.a.boom.v.d.velde@tue.nl

Payment

The cost of the attendance of the symposium amounts to €100,- (one day, NNV-member), €120,- (one day, non-NNV-member), €160,- (two days, NNV member), and €200,- (two days, non-NNV member). The fee is to be paid after the meeting on the basis of an invoice sent to you personally or to your institute/company. Payment by cash at the registration is not possible. Registration deadline is February 20, 2012. If you cancel after this date, you will still be charged the full fee. If you register after this date, accommodation cannot be guaranteed.

Summaries

The summaries of all the contributions are coded as follows:

M: main presentations of 40 minutes by invited speakers.
O: contributions selected for oral presentation, (20 minutes).
A/B: contributions selected for poster presentation.

Each oral presentation includes at least five minutes for discussion.
There will also be an opportunity to present the orals as posters. Please bear in mind that many people in your audience will be students and colleagues from other disciplines.

Poster presentation

The size of the *poster* is 841 x 1189 mm (A-0). The poster session will take place on Tuesday morning and Wednesday morning. You are kindly requested to stay with your poster for as long as possible.

Poster prize and Oral prize
Once again there will be a prize for the best poster and for the best oral.
The jury for the poster and oral prizes consists of members of the organizing committee.

How to reach Lunteren?
Lunteren has its own railway station, which can be reached from the directions Amersfoort (Utrecht) and Ede-Wageningen. You can find the train time tables on: www.ns.nl/reisinfo. The conference center is a 10 to 15 minute walk away from the station. Call 0318-484555 for a taxi.

PROGRAMME & ABSTRACTS

Programme Tuesday March 6 – 2012

09.45 – 10.20		Registration and coffee
10.20 – 10.30		Welcome (Africa-zaal)

Numerical Modelling (session leader Jan van Dijk)

10.30 – 10.35		Intro
10.35 – 11.15	M1	**Prof.dr. W.J. Goedheer / FOM-Instituut voor Plasmafysica te Rijnhuizen** *Numerical Modelling for Pilot-PSI and Magnum-PSI, the "num" of Magnum*
11.15 – 11.35	O1	**Gideon Wormeester** *Streamer simulations with highly accurate transport data : Effects and applications*
11.35 – 11.55	O2	**Jonathan Citrin** *Quasilinear transport modeling at low magnetic shear*
11.55 – 12.15	O3	**Efe Kemaneci** *Error Assesment for Quasi-Steady States of Collisional Radiative Models via Chemical Reduction Technique: Application to Ar and Hg Plasmas*
12.30 – 13.45		**Lunch**
13.45 – 14.10		**Single Slide Show (Africa-zaal)**
14.10 – 15.45		**Poster session 1 (Azië-zaal)** **A 1 t/m A 25** Coffee and tea during session

Diagnostics (session leader Tony Donné)

15.45 – 15.50		Intro
15.50 – 16.30	M2	**Prof.dr. P. Awakowicz / Ruhr-Universität Bochum** *Plasma Diagnostics of Atmospheric Microplasmas*
16.30 – 16.50	O4	**Simon Hübner** *Thomson scattering on transient microwave induced plasmas*
16.50 – 17.10	O5	**Hugo van den Brand** *The application of ECE as sensor in a control loop for the suppression of instabilities on ITER*
17.10 – 17.30	O6	**Bram van Gessel** *Measuring the gas temperature in an atmospheric pressure plasma by spectroscopy*
18.15 – 20.00		Dinner

Evening Lecture

20.00 – 21.00	**Dr.ir. Y.A.W. de Kort / Eindhoven University of Technology, Department of Industrial Engineering & Innovation** *"Light and the mind"*

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Programme Wednesday March 7 – 2012

07.30 – 08.30		Breakfast

Extreme Plasmas (session leader Guus Pemen)

08.30 – 08.35		Intro
08.35 – 09.15	M3	**Assoc. Prof. R. Scholten / School of Physics / The University of Melbourne** *Arbitrarily shaped ultrafast high coherence electron bunches from cold atoms for coherent diffractive imaging at the nanoscale*
09.15 – 09.35	O7	**Marc van Dijk** *The Photonic Free-Electron Laser: Coherent Cerenkov Radiation from Photonic Crystals*
09.35 – 09.55	O8	**Peter Smorenburg** *Heating and expansion of radio frequency driven ultracold plasmas*
09.55 – 10.15	O9	**Tom Huiskamp** *Temperature and pressure effects on the properties of positive streamers in air*
10.15 – 10.40		**Single Slide Show (Africa-zaal)**
10.40 – 12.15		**Poster session 2 (Azië-zaal)** **B 1 t/m B 25** Coffee and tea during session
12.30 – 13.45		**Lunch**

Applications (session leader Peter Bruggeman)

13.45 – 13.50		Intro
13.50 – 14.30	M4	**Prof.dr.ir. W.M.M. Kessels / Eindhoven University of Technology, Department of Applied Physics** *Plasma-assisted atomic layer deposition for processing at the nanoscale*
14.30 – 14.50	O10	**Paul Blom** *Steady progress on laser-assisted discharge produced plasma (LDP) technology*
14.50 – 15.10	O11	**Stephan Welzel** *Gas phase IR absorption studies of air-like atmospheric pressure DBDs*
15.10 – 15.30	O12	**İlker Doğan** *The origin of bimodal size distribution of silicon nanocrystals synthesized in a remote expanding thermal plasma*
15.35 – 16.00		**Presentation NNV-prizes for ‘Best Poster 2012’ and ‘Best Oral 2012’**

Summary poster session 1 / March 6/ 2012

A1 Determination of localized heat transport in fusion plasmas
A2 Hot restrike of High Intensity Discharge Lamps
A3 CO_2 Conversion in an Atmospheric Pressure DBD
A4 External RF substrate biasing during μc-Si:H film deposition
A5 First magnetized plasmas in the linear plasma generator Magnum-PSI
A6 A stabilizing effect of flow shear due to the Coriolis effect in rotating magnetized plasmas
A7 Design trade-offs of an ITER LIDAR spectrometer
A8 How to characterise an Extreme Ultra-Violet generated plasma
A9 Burn control with confinement time actuation
A10 Knudsen cell as a high-flux atomic beam source for alkali metals
A11 On the role of ions during microcrystalline silicon deposition in the high-pressure-depletion regime
A12 Period control in nuclear fusion plasmas
A13 Embedding Poisson equation into a time-dependent problem for the steady-state problem
A14 Characterization of plasma-deposited polycrystalline silicon thin films
A15 Computational analysis of a new high brightness ion source
A16 Measuring microwave stray radiation in the W7-X stellarator
A17 Waves in Plasma: Analysis of Dispersion Relation for High Frequency Waves in a Cold Magnetized Plasma
A18 Plasma Assisted CO_2 reduction for synthetic fuels
A19 The Energy Balance of Hg-free HID lamps and the influence of electrode distance
A20 Carbon Transport and Escape Fraction in a High Density Plasma Beam
A21 Finite Difference Schemes for Anisotropic Diffusion
A22 Breakdown processes in a gas discharge
A23 The effect of particle recombination in subsonic expanding Argon plasmas
A24 Dust particle formation in argon-acetylene plasmas and interaction with (extreme) ultraviolet radiation
A25 Pilot-PSI simulations using the coupled B2.5-Eunomia code

Summary poster session 2 / March 7/ 2012

B1 Decontamination of burn wounds using a cold atmospheric pressure plasma jet
B2 Stability study of high harmonic generation in a capillary for seeding of free-electron lasers
B3 Oxidative degradation of toluene and limonene in air by pulsed corona technology
B4 Electrical and Optical Diagnostics of an RF and a Nanosecond Pulsed DC Cold Atmospheric Pressure Plasma Jet for Biomedical Applications
B5 High-speed photography of long laboratory sparks
B6 Towards understanding terrestrial gamma-ray flashes (TGFs),hard x-rays and positron production in thunderclouds
B7 High order fluid model for ionization fronts in streamer discharges
B8 OH radical density measurements in a cold RF atmospheric pressure plasma jet
B9 In-situ mapping of 3D material flux in PLD plasmas
B10 The influence of laser parameters in Pulsed Laser Deposition thin film growth
B11 Towards user-friendly, public domain streamer discharge simulation software
B12 Particle based 3D modelling of streamer discharge inception
B13 Boosting the recovery rate of plasma switches by application of a supercritical state liquid as switching medium
B14 Direct synthesis of Hydrogen Peroxide in the gas phase using ambient pressure Microplasmas
B15 Measuring the ozone concentration in the effluent of an APPJ by UV absorption spectroscopy
B16 Extreme ultraviolet source based on high harmonic generation from ions for the direct seeding of Free Electron Lasers
B17 Reduced bandwidths for soft-x ray reflection using Lamellar Multilayer Gratings
B18 An Ultracold Electron Source for Ultrafast Electron Diffraction Experiments
B19 The Balmer line radiation of Pilot-PSI modeled with a collisional radiative model
B20 Surface Discharges on Glass and Strontium-Titanate
B21 Laser based diagnostics at Magnum-PSI
B22 Modelling of a coaxial plasma line source
B23 Fluctuation dynamo driven by shear-bursts
B24 Bifurcation to the H-mode
B25 Bifurcation theory for L-H transition dynamics in fusion plasmas

M 1

Numerical Modelling for Pilot-PSI and Magnum-PSI, the “num” of Magnum

W.J. Goedheer, R.C. Wieggers, G.A. van Swaaij, and K.S.C. Peerenboom
FOM Institute DIFFER – Dutch Institute for Fundamental Energy Research, Association EURATOM-FOM, PO Box 1207, 3430 BE Nieuwegein, The Netherlands, www.differ.nl

Magnum-PSI and Pilot-PSI produce linear plasma beams with properties similar to those expected in the divertor of ITER, where the outer layers of the plasma are diverted onto heat resistant tiles. Typical conditions are a high density (>10^20 m^-3, a low temperature (<10 eV), and extreme particle and energy flux densities (>10^24 m^-2s^-1 and >10MWm^-2, respectively). Modelling of these plasmas requires a multi-fluid description of the plasma species and a kinetic description of the neutral species. Molecules and atoms have a mean free path exceeding typical gradient lengths and play a significant role in the plasma recycling. An important issue is validation of the available models, via benchmarking against other models, but especially against experiments. At DIFFER, we have developed Eunomia, a Monte Carlo code for the neutral species that recently has been coupled to B2.5, a multi-fluid plasma model. Application to Pilot-PSI and Magnum-PSI provides us with a thorough validation, via plasma properties and via spectroscopy.

The cascaded arc source of Pilot-PSI and Magnum-PSI runs at a relatively high pressure, while the plasma expands in a low pressure region. The expansion is hampered by the strong applied axial magnetic field. In collaboration with the PLASIMO team at the Eindhoven University of Technology, we model the arc and the initial expansion. Topics are the multi-species plasma and the influence of the nozzle geometry.

The harsh conditions at the strike point of the plasma cause erosion of the plasma facing components. This holds especially if carbon is the main material of the divertor tiles. Knowledge about the erosion and redeposition of material is a crucial ingredient for the design of the divertor. ERO, an impurity tracing Monte Carlo code, following atoms and molecules released from the surface, is used to study erosion and redeposition in Pilot-PSI and Magnum-PSI. An important issue addressed is the number of photons emitted per released hydrocarbon molecule. For this, dedicated experiments using a methane gas puff are simulated. Impurity tracing codes like ERO require erosion yields as input. Molecular Dynamics simulations of the surface bombardment with ions could provide this, but are challenging because the response of the surface to the intense bombardment needs to be taken into account.

Since we use models that can also be applied to the divertor geometry of ITER and DEMO, the results of our research can readily be transferred to the fusion community.

An overview will be given of recent results in the areas discussed above.

M 2

Plasma Diagnostics of Atmospheric Microplasmas

P. Awakowicz, N. Bibinov, P. Rajasekaran, R. Pothiraja
Ruhr-Universität Bochum

Atmospheric non-equilibrium micro plasmas offer many interesting applications for deposition of coatings, surface activation or medical treatment but their behaviour is by far not understood. Therefore their characterization is highly desirable and necessary to investigate and develop new applications or get an approval for medical instruments.

The talk will show how to couple quantitative spectroscopy and simulation in order to measure the fundamental plasma parameters, species concentrations and their corresponding fluxes. Some ideas will be given how to describe plasma chemistry for coating plasmas and which parameters may influence their application to biomedical treatment of skin.

M 3

Arbitrarily shaped ultrafast high coherence electron bunches from cold atoms for coherent diffractive imaging at the nanoscale

RE Scholten, AJ McCulloch, DJ Thompson, D Murphy, C Putkunz and DV Sheludko
ARC Centre of Excellence for Coherent X-ray Science, School of Physics,The University of Melbourne, Australia, scholten@unimelb.edu.au

Ultrafast electron diffractive imaging can provide valuable information on dynamic processes at the nanoscale, but requires a high-brightness source. The effective brightness of electron sources has been limited by non-linear divergence caused by repulsive interactions between the electrons, known as the Coulomb explosion. It has been shown that electron bunches with ellipsoidal shape and uniform density distribution have linear internal Coulomb fields [1], which allows for reversal of the Coulomb explosion using conventional optics. Charged particle sources based on photoionisation of laser cooled atoms can in principle create bunches shaped in three dimensions and hence achieve the transverse spatial coherence and brightness needed for picosecond diffractive imaging with nanometre resolution.

We have recently demonstrated [3] such arbitrary shaping of the cold atom cloud, and hence of the extracted electron bunches, and used the shaping capability to allow detailed measurement of the spatial coherence properties of the cold electron source [4]. We also show remarkable ion bunch shape formation and evolution, with direct visualisation made possible by the very cold (milli-Kelvin) ions. Using two-step coherent excitation with a femtosecond laser from ground to excited state, and a nanosecond laser from excited state to the continuum, we have produced sub-nanosecond electron pulses. Diffraction experiments of simple crystalline materials are currently in progress, to demonstrate application of the high coherence of the novel source.

In separate work [5], we have demonstrated coherent diffractive imaging with electrons in scanning transmission electron microscopy. Future development of the cold atom electron source will increase the bunch charge and charge density, demonstrate reversal of Coulomb explosion, and picosecond pulse durations, and ultimately, ultrafast coherent electron diffractive imaging.

[1] OJ Luiten, SB van der Geer, MJ de Loos, FB Kiewiet and MJ van der Wiel, *Phys. Rev.Lett.* **93**, 094802 (2004).
[2] BJ Claessens, SB Van der Geer, G Taban, EJD Vredenbregt,and OJ Luiten. *Phys. Rev. Lett.* **95** 164801 (2005).
[3] McCulloch, A. J., Sheludko, D. V., Junker, M., Bell, S. C., Saliba, S. D., Nugent , K. A. and Scholten, R. E. *Nature Physics* **7** 785 (2011).
[4] SD Saliba, CT Putkunz, DV Sheludko, AJ McCulloch, KA Nugent and RE. Scholten, *Optics Express* **20** 3967 (2012).
[5] CT Putkunz, AJ D'Alfonso, AJ Morgan, M Weyland, C Dwyer, L Bourgeois, J Etheridge, A Roberts, RE Scholten, KA Nugent and LJ Allen, *Physical Review Letters* (in press).

M 4

Plasma-assisted atomic layer deposition for processing at the nanoscale

W.M.M. Kessels
Plasma & Materials Processing (PMP) group, Department of Applied Physics, Eindhoven University of Technology, The Netherlands

Atomic layer deposition (ALD) is a deposition method based on alternating surface chemical reactions in which the self-limiting growth behavior allows for the deposition of ultrathin films with Ångstrom-level resolution and with a high conformality on demanding 3D surface topologies. In plasma-assisted ALD, the use of plasma species during one step of the cyclic deposition process allows for more freedom in processing conditions and for a wider range of material properties compared with the conventional thermally-driven ALD method. Due to the continuous miniaturization in the microelectronics industry and the increasing relevance of ultrathin films in also many other applications the deposition method has rapidly gained popularity in recent years. In this contribution, plasma-assisted ALD processes for applications such as nanoelectronics, solar cells and catalysis will be addressed. Surface reaction mechanisms as obtained from in situ studies will be presented and the plasma-surface interaction, e.g., ion bombardment, VUV plasma damage, and surface-mediated radical recombination, will be considered in detail.

Evening Lecture

Light and the mind

Yvonne de Kort
Associate professor Environmental psychology Human-Technology Interaction group, School of Innovation Sciences Eindhoven, University of Technology, PO Box 513, 5600 MB Eindhoven, the Netherlands

Light is a wondrous phenomenon, part wave, part particle. But light's most intriguing characteristics pertain to the effects it has on human functioning. It has been claimed to help us concentrate and perform better on tasks; we use it liven up our parties, or to seduce our desired partner; it is said to impact physical and mental health. In this evening lecture, we will touch upon a number of such effects. We will cover findings from perception research, psychology and even biology to illustrate just how interesting and incredibly important this physical phenomenon is for the human psyche.

O 1

Streamer simulations with highly accurate transport data: Effects and applications

G. Wormeester,[1] S. Dujko[2], S. Nijdam[3], U. Ebert[1,3]
[1]*Centrum Wiskunde & Informatica, Amsterdam*
[2]*Institute of Physics, University of Belgrade*
[3]*Department of Applied Physics, Eindhoven University of Technology*

Streamers are thin channels of ionized gas that are of importance in natural phenomena such as lightning and sprites as well as industrial applications such as lighting and gas cleaning. We have extended our existing simulation code with highly accurate transport data. This transport data was obtained from a multi-term Boltzmann equation solver. Popular publicly available Boltzmann solvers such as BOLSIG+ are limited to a two term approximation. We have investigated the effect of transport data on streamer parameters such as velocity, diameter and electric field profiles. Furthermore, we now also study the propagation of streamers in atmospheres of other planets and make predictions for the occurrence of sprite discharges on these planets with use of these appropriate transport data.

O 2

Quasilinear transport modeling at low magnetic shear

J.Citrin[1], C.Bourdelle[2], P.Cottier[2], D.F.Escande[3], Ö.D.Gürcan[4], D.R.Hatch[5], G.M.D.Hogeweij[1], F.Jenko[5], M.J.Pueschel[5]

[1]*FOM Institute DIFFER -– Dutch Institute for Fundamental Energy Research, Association EURATOM-FOM, Nieuwegein, The Netherlands*

[2]*CEA, IRFM, F-13108 Saint Paul Lez Durance, France*

[3]*UMR 6633 CNRS-Universitè de Provence, Marseille, France*

[4]*Laboratoire de Physique des Plasmas, Ecole Polytechnique, CNRS, 91128 Palaiseau Cedex, France*

[5]*Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany*

The accurate prediction of turbulent transport through numerical modeling is one of the central themes in fusion physics. This is vital for both the interpretation of present-day tokamak experiments and extrapolation to future devices. However, the extreme computational requirements of full non-linear simulations require the development of simpler models for routine transport prediction. This work reports on the extension of a computationally inexpensive quasi-linear transport model to low magnetic shear parameter space. The quasi-linear predictions are compared with non-linear simulations using a gyrokinetic code. The non-linear results provide new insight into the physics of tokamak turbulence at low magnetic shear. This has been critical to guide the assumptions made in the quasi-linear model and thereby to improve the correspondence between the quasi-linear model and the full non-linear simulations.

O 3

Error Assesment for Quasi-Steady States of Collisional Radiative Models via Chemical Reduction Technique: Application to Ar and Hg Plasmas

E.H. Kemaneci, J. van Dijk, G.M.W. Kroesen
Group Elementary Processes in Gas Discharges, Eindhoven University of Technology

Conventional Collisional Radiative Models (CRMs) lessen the computational load of simulating reactive flows by assuming that most of the plasma species are in Quasi Steady State (QSS) [1]. For such species the solution of transport equations can be avoided. However, the traditional formalism lacks a good measure of the error that is made by this approximation.

In order to fill this gap, a relation is established between the CRM method and the Chemical Reduction Technique (CRT) [2,3]. Both methods have the same goal: to reduce the number of transport equations without eliminating reaction channels. The reduction technique is based on the diagonalisation of the source jacobian. It allows a more precise assessment of the errors induced by the QSS assumption. By diagonalisation, the problem is rewritten in terms of linear combinations of the species densities, whose evolution in time is characterised by decay times that are related to the corresponding eigenvalues.

In this contribution, the application to both atomic Ar and Hg plasmas is discussed. The results show agreement with the CRM literature [1]. For common plasma parameters, only the atom and ion ground state densities need to be dealt with explicitly, while the other (excited) states can be assumed to be quasi-steady. A detailed analysis of the error will be provided.

[1] Dijk J van, Hartgers A, Jonkers J, Mullen J J A M van der (2001) Collisional radiative models with multiple transport-sensitive levels- application to high electron density mercury discharges.Journal of Physics D: Applied Physics, 34(10), 1499-1509
[2] Eggels R L M G (1996) Modelling of Combustion Processes and NO Formation with Reduced Reaction Mechanisms PhD Thesis Eindhoven University of Technology
[3] Pope S B, Maas U (1992) Simplifying chemical kinetics: Intrinsic low dimensional manifolds in composition space. Combustion and Flame, 88:239-264

O 4

Thomson scattering on transient microwave induced plasmas

S. Hübner, E.A.D. Carbone, J.M. Palomares, J.J.A.M. van der Mullen
*Department of Applied Physics, Eindhoven University of Technology,
The Netherlands*

In this study we investigate power-pulsed microwave plasmas at low pressure. The plasma is created by a surfatron launcher in argon and argon mixtures. Various microwave power-pulse lengths and frequencies were employed.

To investigate the immediate response to the power-pulse we use time resolved Thomson scattering (TS). This laser scattering technique provides simultaneously the electron density and temperature of the plasma.

During the pulse rise we observe high values of the temperature, while the density is still rising. Steady-state like condition is reached in several milliseconds depending on the pressure. The unusual short decay time of about 40 µs in the argon plasma afterglow in comparison to diffusion losses reveals that the dominant decay mechanism in our pressure regime is provided by molecular assisted recombination.

O 5

The application of ECE as sensor in a control loop for the suppression of instabilities on ITER

H. van den Brand [1a,2] , M.R. de Baar [1b,2], N.J. Lopes Cardozo[1a] and E. Westerhof
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Control of performance limiting instabilities will be essential for the successful exploitation of the ITER experiment. A particular example is provided by the neoclassical tearing modes (NTMs), which manifest themselves in reconnection of magnetic field lines, leading to so-called magnetic islands. ITER is envisaged to be equipped with a real-time control system using electron cyclotron current drive (ECCD) as actuator.

An analysis is made of the requirements for real-time NTM suppression. The required accuracy in ECCD deposition position and maximum allowed latency, between island creation and start of ECCD, are derived through modeling of island growth and island rotation.

A possible sensor for the detection of the presence and location of magnetic islands is electron cyclotron emission (ECE). The use of ECE observed either in the equatorial plane or along the line of sight of the ECCD launcher is assessed through detailed analysis of simulated diagnostic signals and their real-time interpretation.

O 6

Measuring the gas temperature in an atmospheric pressure plasma by spectroscopy

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Eindhoven University of Technology, Department of Applied Physics, group EPG,
P.O. Box 513, 5600 MB Eindhoven

Optical emission spectroscopy (OES) is a common method to measure the temperature of a plasma. Rotational spectra of molecules inside the plasma can be measured in a relatively simple and non-intrusive way. If the rotational lines follow a Boltzmann distribution the temperature can be obtained. But is this temperature really the gas temperature? A different method for obtaining rotational spectra is laser induced fluorescence (LIF), where the emission of a species is measured after it has first been excited by a laser. LIF is a sensitive technique to specifically measure temperatures and densities of species locally in a plasma. We compared these two techniques in an atmospheric pressure microwave plasma jet of helium and air. Using LIF we measured the concentration and temperature of nitric oxide (NO), and with OES we measured the temperature of NO and N_2. While both techniques are used in literature to measure gas temperatures, we found that the resulting temperatures are not consistent.

O 7

The Photonic Free-Electron Laser: Coherent Cerenkov Radiation from Photonic Crystals

M. W. Van Dijk, T. Denis, J.H.H. Lee, P.J.M. van der Slot, K.-J. Boller
Laser Physics and Nonlinear Optics,Mesa+ Institute for Nanotechnology, Department of Science and Technology, University of Twente

Photonic crystals (PhCs) allow generation of light in completely novel ways. Particularly interesting is the Cerenkov radiation generated by free electrons sent through a PhC. The modifications to spontaneous Cerenkov emission introduced by a PhC have been analyzed theoretically [1] and spontaneous Cerenkov emission has also been observed experimentally using 20 to 40 keV electrons [2]. To obtain coherent Cerenkov radiation, the electron beam current and length of the PhC should be significantly larger.

Here, we present a numerical study of coherent Cerenkov emission inside a photonic crystal. Particle-in-cell modeling has been performed for a photonic free-electron laser operating around 15 GHz and pumped by a single electron beam. We observe coherent Cerenkov emission for electron energies between 10 keV to 15 keV when the laser is driven by a beam current of 1 A. Coherent Cerenkov emission should occur at a frequency where the electron and radiation phase velocities are about equal. However, the emitted frequency in the simulations is significantly lower. This discrepancy can be explained by (i) the space-charge depression of the electron beam electrostatic potential that results in a lower average electron velocity, and (ii) the collective Coulomb interaction that results in plasma waves propagating along the electron beam. Both effects lower the emission frequency.

[1] C. Luo et al., “Cerenkov Radiation in Photonic Crystals,” Science **299**, 368–371 (2003).
[2] G. Adamo et al., “Light Well: A Tunable Free-Electron Light Source on a Chip”, Phys. Rev. Lett. **103**, 113901 (2009).

O 8

Heating and expansion of radio frequency driven ultracold plasmas

P.W. Smorenburg, L.P.J. Kamp, and O.J. Luiten
Eindhoven University of Technology, Department of Applied Physics,
The Netherlands

Ultracold plasmas (UCPs) can be created by photo-ionization of a cloud of laser-cooled atoms. This results in a millimeter-sized plasma cloud with an electron temperature close to 1K, making UCPs unique plasma systems. Because UCPs are nearly in the strongly coupled plasma regime, they can serve as easily accessible and well-controlled model systems for other strongly coupled plasmas such as solid state laser targets. To reliably simulate both a solid target and a laser field, one should apply a radiofrequency (RF) field to the UCP. In current UCP experiments, RF fields are already used to probe collective plasma modes. In view of these applications, a detailed understanding of the interaction between UCPs and RF fields is necessary. We investigate the influence of an RF field in a number of plasma processes that are important for the temperature and expansion rate of an UCP. It turns out that the kinetic energy of the quiver motion induced by the RF field replaces the electron temperature in the functional dependency of, for instance, the electron-ion collision frequency, Coulomb integral, and three body recombination (TBR) rate. The UCP absorbs energy from the RF field by the well-known process of collisional absorption, which depends on the ratio between the quiver energy and the temperature. In addition, the finite plasma size gives rise to collisionless RF absorption if the electron temperature passes a critical value. Finally, usually the process of TBR is a major heat source in UCPs due to the low temperature. However, the TBR rate can be strongly suppressed by application of an RF field. All of these processes play an important role in the heat budget of the UCP, and therefore the RF field influences the rate of the thermally driven expansion in multiple ways.

O 9

Temperature and pressure effects on the properties of positive streamers in air

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We present experimental results on how the properties of positive, pulsed streamers in air depend on *E/N* (*in V/cm*^{2}). Streamers are generated in a wire-cylinder reactor at constant voltage (so constant *E*). The density is changed either by varying the temperature (20-500 ^{o}C) at constant pressure (1000 mbar), or by varying the pressure (379-1000 mbar) at constant temperature (ambient temperature). A fast ICCD-camera (200 ps shutter-time) is used to analyze the spatial and temporal development of the streamers.

As an example, Fig. 1 shows the average streamer velocity as function of *E/N*. Increasing *E/N* results in higher energy-per-pulse and faster streamer development. A significant difference can be observed when changing the density by varying the temperature (black line), or by varying the pressure (grey line). The temperature effect is much more pronounced than the density effect. We will discusses these observations and compare them with findings in literature.

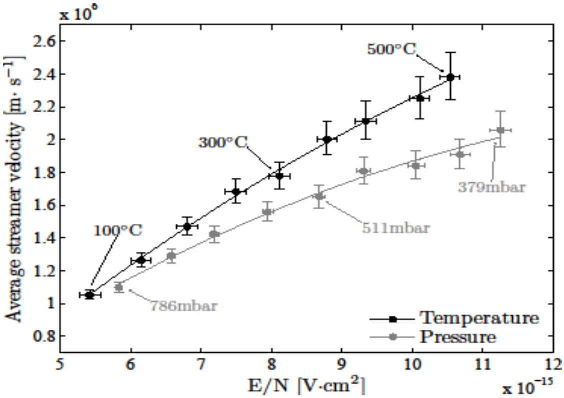

Fig. 1 Streamer velocity when varying *E/N* by temperature (black line) or by pressure (grey line)

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O 10

Steady progress on laser-assisted discharge produced plasma (LDP) technology

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Delivering light sources for extreme ultraviolet lithography (EUVL) for more than 10 years, XTREME technologies GmbH is now focused on developing powerful and stable EUV sources that will enable EUVL to transition to high volume manufacturing (HVM). A paradigm shift, EUV raises new challenges demanding performance to increase by several orders of magnitudes. Scalable in terms of optical power and lifetime, XTREME technologies' innovative LDP (Laser-assisted Discharge Plasma) technology combines the specific advantages of the formerly developed LPP (laser produced plasma) and DPP (discharge produced plasma) technologies while overcoming the inherent limitations of those.

As a hybrid technology, LDP uses both a laser and an electrical discharge. The Tin fuel is provided by liquid Tin baths wetting the surface of rotating wheels. Those Tin films are forming the electrodes. A trigger laser of moderate energy evaporates a small amount of Tin from the thin film without damaging the wheels themselves. A capacitor bank then discharges a high voltage/high current into the Tin cloud (see schematics below). Self pinching, a hot dense plasma is generated between the two electrodes. When relaxing to a lower energy state, the plasma emits EUV radiations as a Planck emitter. A long life grazing incidence mirror - protected with a Foil Trap from the damaging debris generated by the plasma - collects and focuses the EUV light towards the scanner. A series of mechanical baffles, together with the Foil Trap, prevent the transport of Tin contaminants towards the scanner and the pellicle-less mask.

Compared to the more traditional purely laser based LPP technology, LDP demonstrates high wall plug efficiency, long lifetimes and high stability. Against the conventional DPP, LDP achieves high electrode lifetime - through the dispersion of the heat load and plasma-wall interaction to a larger and regenerative electrode surface - and offers a path to high power scalability. Also, the small thickness of the Tin film covering the rotating wheels enables mass limited operation i.e. a significant reduction of the amount of debris generated by the source.

O 11

Gas phase IR absorption studies of air-like atmospheric pressure DBDs

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Diffusive dielectric barrier discharges (DBDs) at atmospheric pressure have been shown to be a promising tool in large-area plasma-enhanced chemical vapour deposition (PE-CVD). If operated in cost-efficient gas mixtures of $Ar/N_2/O_2$ and organo-silicon precursors excellent barrier layers on polymeric substrates during large-area plasma-enhanced chemical vapour deposition (PE-CVD) have been obtained. Different regimes of plasma-polymer interaction along the electrodes have been identified which are mainly characterised by a competition between deposition and etching processes.

This contribution is concerned with the gas phase composition of the exhaust in an industrially relevant roll-to-roll configuration. Given the challenging optical access to such type of plasmas a gas sampling system was implemented which collected a fraction of the effluent into a multiple pass absorption cell. The gas composition was analysed by a Fourier-Transform-Infrared (FT-IR) spectrometer. The identification of main stable species enabled the NO_x chemistry in the presence of hydrocarbons to be discussed. A dominant etching process of the polymer in air-like gas mixtures is thereby characterised by key species which are present in the effluent.

O 12

The origin of bimodal size distribution of silicon nanocrystals synthesized in a remote expanding thermal plasma

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Unique properties present in confined Silicon Nanocrystals (Si-NCs) like size dependent luminescence, improved charge storing capacity and increased surface reactivity have generated interest in a variety of different applications. These properties have proven to be dependent on both the size of the nanocrystal and the nature of its interface. For successful applications, the main issues of Si-NC synthesis are size control, surface engineering for improved optical properties, and high throughput processing. Among these points, the amount of throughput is highly critical for large scale applications however, this is not possible to achieve with current production techniques. Our research goal is to show that it is possible to fulfill these demands with a novel route by using the remote expanding thermal plasma (ETP) technique. This technique is observed to result in a very high throughput of about 25 mg/minute. However, we observed a bimodal size distribution with smaller particles (3-10nm) formed in the central portion of the plasma jet and larger particles (40-140 nm) formed in recirculation regions in the reactor. To move towards a better control of the size distribution a 10 cm diameter quartz tube is placed around the central plasma jet, confining the central region and hindering the generation of the recirculation zones. Results of experimentation in the tube configuration indicate the suppression of larger nanoparticle growth, however isolated large Si NPs are still observed with TEM. Further efforts to eliminate larger Si NPs from the synthesized powder focus on the use of pulsing silane into the reactor on the millisecond timescale with the aim of consuming the silane on a timescale faster than that of large nanoparticle growth, thus inhibiting their formation. First results show that growth of nanocrystals is nucleation controlled. Furthermore, the large size crystals are not the result of coalescence of smaller size particles, as evidenced from TEM measurements.

A 1

Determination of localized heat transport in fusion plasmas

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In fusion reactors such as tokamaks and stellarators high temperatures, densities, and low thermal transport are needed to create the conditions for nuclear fusion.
In this paper we suggest a method to identify the diffusion coefficient, the damping term and the convection velocity. This is possible by perturbing the plasma with a localized heat source, in this case Electron Cyclotron Resonance Heating (ECRH) and measuring the resulting temperature fluctuations locally by means of Electron Cyclotron Emission (ECE). Using ECE and ECRH, we developed a new method to estimate the different components of the one-dimensional radial heat transport as function of the radius. Although this method is not tested on real data yet, it was possible, using a finite difference model taking noise into account, to estimate the local diffusion coefficient, damping term and convection velocity in slab geometry. The method is easily extendable to cylindrical geometry. In addition it is possible to test with this method if the physics model describes the data well. If so, we can give uncertainty bounds on the estimated parameters. These uncertainty bounds are a mapping of the uncertainty of the measurements to the parameter uncertainty. This new methodology will give insight into the local heat transport inside fusion plasmas and hopefully allows us to identify and control internal transport barriers in the future.

A 2

Hot restrike of High Intensity Discharge Lamps

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High Intensity Discharge (HID) lamps that operate at high pressure and temperature, and create light from a relatively small volume have found many applications such as outdoor lightning, xenon car headlights, and lightning in shops. The light of HID lamps is produced by radiating plasma which typically contains a noble gas, mercury and salts. The salts are important to make the plasma radiate efficiently in the visible spectrum.

One of the main disadvantages of HID lamps in comparison with other light sources at the moment is its ignition. Like all plasma based light sources is the voltage required to ignite a HID lamp much higher than during stable operation of the lamp; especially in cases of re-ignition when the lamp is still hot. This high voltage requirement for re-ignition of the lamp makes the power supply expensive and environmentally unfriendly.

A possible solution to lower this high ignition voltage is to locally enhance the electric field with antennas. This can be done by wiring conducting channels around the lamp or draw a conducting path on the lamp. The effect of antennas on the ignition process of discharges in 150 mbar Ar filled lamps with trace amounts of Hg has been investigated. The electrode gap is 7,15mm, and high frequency AC voltage is used for the ignition process. We discovered a reduction in ignition voltage of HID lamps when the antennas are present.

A 3

CO_2 Conversion in an Atmospheric Pressure DBD

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We present a promising approach for the conversion of CO_2 to CO. The CO_2 dissociation is the process limiting step if the following global carbon cycle is to be considered: convert CO_2 into CO and add $H_2(O)$ to get a syngas-like mixture. This can be used to produce hydrocarbons such as fuels, solvents and plastics via conventional routes such as Fischer-Tropsch synthesis or in plasma-assisted processes. Finally the hydrocarbons can be burned to CO_2 and H_2O to use the energy stored in the C-H bonds, and/or recycle the polymers after use.

Our present approach focuses on an atmospheric pressure dielectric barrier discharge (DBD) to perform plasma assisted conversion of CO_2 to CO and O_2. One of the aims of the project is an overall high energy efficiency: therefore special attention is paid to the matching network of the DBD reactor and its electrical characterization. Different methods of determining the injected energy will be compared. To study the breakdown mechanisms the optical emission of the plasma is recorded time as well as spatially resolved. Guidelines to optimize the process conditions will be discussed.

A 4

External RF substrate biasing during µc-Si:H film deposition

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Hydrogenated microcrystalline silicon (µc-Si:H) has found use as intrinsic absorber layer in thin-film solar cells thanks to its enhanced absorption of infrared light and optoelectronic stability compared to amorphous silicon (a-Si:H). However, thicker (≥1µm) µc-Si:H layers are required to achieve sufficient light absorption (1), making the deposition rate an important parameter along with the quality of the deposited layer. The Expanding Thermal Plasma (ETP) (2) (3) is a technique with which high deposition rates (≥ 1nm/s) can be obtained, but the deposited films have been porous and of low quality (4) (5) (6). Due to its remote plasma structure, the ETP technique leads to very small ion energies (1-2 eV) (7). Although high energetic ions are responsible for an amorphization of the growth (7) and incorporation of defects (8), a moderate ion energy is believed to enhance thermal activation on the surface and displacement of atoms to favorable sites leading to denser and higher quality films (7) (9). Furthermore, device-grade µc-Si:H layers are grown in a narrow parameter range corresponding to the transition regime from a-Si:H to µc-Si:H (1). Recently, Fourier transform infrared (FTIR) spectroscopy has been shown to provide insight to the quality of the film without having to integrate the deposited layer in a real solar cell stack (8) (10). The absorption spectra reveal information on the total hydrogen content in the film and the spread of hydrogen atoms in different zones such as vacancies, voids and crystalline grain boundaries represented by Stretching Modes (SM) (11) (4).

In this study, an external rf substrate bias was applied with the aim to tune ion-surface interactions. The effect of the substrate biasing on material properties was investigated with FTIR and Raman Spectroscopy. Mass Spectroscopy and Optical Emission Spectroscopy were used to analyze the plasma conditions and to verify the extent of additional plasma generated by the biased substrate.

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A 5

First magnetized plasmas in the linear plasma generator Magnum-PSI

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Magnum-PSI is a linear plasma generator constructed at the FOM Institute DIFFER. This machine will be used to study Plasma-Surface Interaction under extreme particle and heat loads, both within the context of fusion research as well as for material research in general. It is designed to provide hydrogen ion fluxes of up to 10^{24} $m^{-2}s^{-1}$, at plasma temperatures in the range of 1 to 10 eV. These ITER relevant parameters are reached using a cascaded arc source to generate the plasma in combination with a strong magnetic field to deliver the plasma to a target plate. A differentially pumped vacuum vessel ensures that plasma losses are kept minimal. Plasma diagnostics include optical emission spectroscopy and Thomson Scattering. In situ target analysis is possible using a suite of surface analysis tools such as a pyrometer and an IR camera. Surface analysis methods such as Laser Induced Desorption and Ablation using a mass spectrometer are being commissioned.

Pending the delivery of its superconducting magnet, Magnum-PSI is presently equipped with a set of copper coils. These coils produce a magnetic field of up to 1.7 T in the plasma source region that diverges to 0.2 T in the target region. The first results on the characterization of the plasma performance in this configuration are the subject of the present contribution.

Thomson Scattering and optical emission spectroscopy were applied to measure the density, temperature and purity of the plasma in the target region of Magnum-PSI. A wide range of conditions was studied in scans of discharge power, gas flow and magnetic field strength. Measured electron densities and temperatures ranged from 0.5 to 10 times 10^{20} m^{-3} 0.3 and 5 eV. Peak hydrogen ion fluxes computed from the electron temperature and density profiles range from 10^{23} to 10^{25} $m^{-2}s^{-1}$, generating heat loads up to 50 MW m^{-2}.

A 6

A stabilizing effect of flow shear due to the Coriolis effect in rotating magnetized plasmas

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In the stability analysis of magnetically confined laboratory plasmas, flow is often neglected. Just like astrophysical plasmas however, laboratory plasmas usually rotate. The centrifugal force can cause an instability similar to that of a fluid on top of a lighter fluid. This instability can be stabilized by a radially decreasing angular rotation frequency [1].

The physical mechanism behind this stabilization will be elucidated by considering a rotating cylindrical plasma, and investigating the stability of non-axisymmetric perturbations with long axial wavelengths. In this case the centrifugal effect, which is responsible for the magnetorotational instability known from astrophysics, is exactly canceled by the stabilizing effect of the rotation shear. The stabilizing effect can be explained as a consequence of a restoring pressure perturbation induced by the radially varying Coriolis force.

In a toroidal geometry, the effect is calculated to be twice as large as the centrifugal effect. The remaining net stabilization of flow shear on linear stability is demonstrated with numerical computations.

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A 7

Design trade-offs of an ITER LIDAR spectrometer

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ITER will use a number of Thomson Scattering (TS) systems, including a core LIDAR diagnostic. The current diagnostic may utilize lasers at both the fundamental and second harmonic YAG wavelengths to fulfill the requirements of both Thomson scattering and calibration. Dual laser calibration provides interesting possibilities for spectral calibration using the overlap of two sets of Thomson scattering spectra, and absolute calibration depending on detector availability. One proposed ITER LIDAR spectrometer layout is based on the MAST spectrometer design. Due to the high etendue captured by the ITER LIDAR system the current spectrometer is expected to be on the order of 2 to 4m. As well as etendue, this large spectrometer size is driven by the need for a low angle on the interference filters. Larger interference filters allow better performance, but are increasingly difficult to manufacture. In the current spectrometer design, a single filter size of between 170mm and 300mm is assumed. The impacts of these different sizes will be examined, as well as the possibility of using different size filters within a single spectrometer. A recently proposed concept is reshaping the etendue from the anticipated narrow longitudinally extended phase-space distribution, to a more condensed trapezoidal distribution by incorporating an axicon lens into the ITER LIDAR design. The ZEMAX optical design code can be used to examine these different optical possibilities. The performance of current designs are sensitive to the wavelength range of scattered light and hence the operating temperature of ITER. Simulations of the performance for different laser configurations and operating scenarios will be considered.

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A 8

How to characterise an Extreme Ultra-Violet generated plasma

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Industries are continuously striving to reduce the size of computer chips in order to meet the demand of increasing computer speed and memory capacity. One way to miniaturize the chips is by reducing the wavelength used in lithography machines by using Extreme Ultra-Violet (EUV, 92 eV) light. The background gas in the lithography machine is partially ionized by the absorption of EUV photons. The study of these low-density (10^{15} m^{-3}) pulsed plasma is experimentally challenging.

We will study EUV-induced plasmas in transparent gasses (e.g. H_2 and He) that show low absorption losses of 0.1-1% per meter around 1 Pa. We want to determine the electron density and therefore the feasibility of several diagnostics (e.g Langmuir and frequency probes, interferometry and microwave scattering) is studied. The most promising diagnostics will be tested on a simulation plasma with similar size and density as the EUV plasma.

A 9

Burn control with confinement time actuation

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Successful operation of future fusion reactors depends on effective control of the burning plasma. Since the fusion reaction is by necessity (largely) self-sustained, auxiliary heating will become a less effective and, moreover, less efficient actuator.

The use of fuelling rate, isotopic fuel tailoring, impurity injection or a combination of the above as input, in both linear and non-linear control schemes, has been proposed.

A possibly more efficient and effective approach would be to use confinement time as an input for control, since this would act on faster time scales than fuel tailoring and eliminate the need for sustained auxiliary heat after the injection of impurities. Possible actuators for confinement time are neutral beam injection (rotation control), non-inductive current drive (q-profile control) or electron cyclotron resonance heating (sawtooth pacing and MHD control).

Starting from a simple, non-linear ordinary differential equation (ODE) model of a burning plasma, we will develop a non-linear controller using confinement time as an input and study its properties such as input sensitivity and robustness for model and parameter uncertainties. For given input limitations we determine which equilibria can be stabilized and what the dynamics of the system are.

A 10

Knudsen cell as a high-flux atomic beam source for alkali metals

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Here we report on the construction of an efficient atomic beam source for rubidium. Rubidium is a favorite atom for laser cooling and trapping applications due to its convenient vapor pressure and a strong optical transition in the near infrared. To create a high-flux atom beam,in general an effusive source operating at an elevated temperature is used. Due to the broad angular intensity distribution, much of the output of the source is wasted. This can lead to substantial alkali-metal contamination unless a so-called recirculating oven design is used, which can be difficult to operate. Recently, however, Bell et al [1] reported on a simpler effusive oven design that uses a long flow restriction to minimize rubidium consumption and optimize beam collimation. Here we describe our progress toward implementing such a source in a high-intensity ion beam apparatus.

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A 11

On the role of ions during microcrystalline silicon deposition in the high-pressure-depletion regime

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Microcrystalline silicon (μc-Si:H) is extensively used in thin-film tandem solar cells. Key issues in the fabrication of μc-Si:H thin films include large area and fast deposition processes. The most commonly used μc-Si:H deposition technique is a capacitively-coupled plasma (CCP) in parallel plate configuration using radio or very high excitation frequency (RF and VHF, respectively). In a CCP high growth rates are obtained by working in the so-called high-pressure-depletion regime (HPD), in which high plasma powers (~0.5 W/cm^2) enable high growth rates through a high silane (SiH_4) depletion and high pressures (>1 mbar) enhance the material properties through a suppressed ion bombardment effect [1, 2]. Despite the good material quality obtained, the role of the ions in plasma-surface interactions is still not completely understood.

In this work, the role of ions in plasma-surface interactions is studied in terms of ion flux and ion energy. By implementing a capacitive probe [3, 4] the ion flux is studied for a range of parameters, i.e. silane flow rate, plasma power and pressure. The ion energy distribution is determined with a retarding field energy analyzer [5,6], although application of this technique is limited to low pressure conditions (<1 mbar).

The ion flux is found to only increase slightly with increasing SiH_4 flow rate (0-10 sccm) and is found to account for 30% of the growth flux. With ion energies below 20eV less than 6eV per deposited Si atom is available. Increment of the plasma power led to an increase in ion flux by two orders of magnitudes, for low plasma powers (<70W), whereas higher plasma powers are characterized by an ion flux of 0.8×10^{15} to 2.0×10^{15} ions/cm^{2}s. When considering pressure, no clear effect is observed, since the measurements are performed in a collisional regime.

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A 12

Period control in nuclear fusion plasmas

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The sawtooth instability, typically present in Tokamak plasmas, is a periodic instability that causes periodic drops in the core temperature. For ITER, the time between two consecutive sawtooth crashes (i.e.\ the natural sawtooth period) will be much too large. In past experiments the sawtooth period has been feedback controlled with a variable electron cyclotron current drive (ECCD) deposition location. Here, recent experiments on TCV are presented where the ECCD power is periodically modulated. Simulations predict that for a range of modulation periods and duty cycles (percentage of power on during modulation) the sawtooth period becomes the same as the power modulation period (i.e. sawtooth locking). Experiments on TCV, show convincing evidence of sawtooth locking thereby confirming the simulations. It appears that for this system open loop control, based on the nonlinear phenomenon of period locking, can be at least as efficient as classical feedback control of the sawtooth period.The experiments confirm that the sawtooth period can be precisely controlled by modulating the ECCD power, without using real-time measurements. For certain combinations of the modulation periods, power levels and duty cycles the sawtooth period becomes the modulation period. In ongoing work this phenomenon is used to design a robust (feedback) controller for the sawtooth period, that is based on power modulation. The locking phenomenon probably also occurs for other dynamical processes in the plasma like ELMs for which similar control methods might also work.

A 13

Embedding Poisson equation into a time-dependent problem for the steady-state problem

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The solution of a steady state discharge is time-independent, but for the computational convenience the time-dependent term is added to the species transport equations. Although they are coupled with the electric field E with Poisson equation, usually they are not solved together due to the huge computational cost but solved consecutively in the way of Gummel iteration. In this procedure if E is treated explicitly, then the time step has a severe restriction for avoiding numerical instabilities. A so-called semi-implicit treatment (Ventzek) can be used to eliminate the time step restriction and ensure stability. Using this technique, the time step can be several orders of magnitude larger than that given by the constraint. But for different numerical method, the numerical flux has different forms, as a result, for different methods this technique should be done in a different way. In this poster we present a simpler way which can avoid the time constraint as well as the semi-implicit treatment from the point of view of mathematics, that is, the potential V is regarded to be time-dependent as well as the species densities. The results of the two treatments are compared.

A 14

Characterization of plasma-deposited polycrystalline silicon thin films

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Polycrystalline silicon (poly-Si) for photovoltaic applications can either be obtained by solid phase crystallization (SPC) of amorphous silicon (a-Si:H), direct deposition or epitaxial thickening of seed layers. The expanding thermal plasma (ETP) technique is able to deposit a-Si:H for SPC at high growth rates. However, SPC annealing times of >10 hours make this process time-consuming.[1,2] Therefore direct deposition of poly-Si by ETP has been investigated. Recently, we have achieved direct deposition of poly-Si on quartz substrates at 800C with an unoptimized deposition rate of 8 nm/s. SEM reveals that there are two phases of film growth: First there is a thin layer (~300 nm) of small crystalline grains, followed by columnar grain growth, leading to large crystalline grains. X-ray diffraction shows that the first phase exhibits a completely random crystal orientation, which is followed by strong preferential (110) growth. From a solar cell point of view, this columnar (110) growth is favorable due to the reduction of grain boundaries encountered by charge carriers traversing the film. Additionally, surface roughness in as-deposited films greatly enhances the light absorption. However, the small grains in the initial layer are detrimental to charge carrier transport. Therefore, a deeper understanding of the mechanism leading to preferential growth seems desirable.

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A 15

Computational analysis of a new high brightness ion source

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Here we report on the computational analysis of a new high brightness ion source by transverse laser cooling of a thermal atomic Rb beam that is effusing from a Knudsen cell. The resulting beam is photo-ionized to create a high-brightness ion beam. Realistic simulations are used to investigate the effect of laser cooling. Further General Particle Tracer (GPT) simulations calculate the disorder-induced heating of the ion beam by taking all pairwise interactions into account. From these simulations we conclude that this new laser-intensified 87Rb+ source can reach a higher reduced brightness than conventional Liquid Metal Ion Sources (LMIS) with, in addition, a lower energy spread.

Sufficient current for milling applications can be generated. When the ion beam is in the pencil-beam regime, brightness can be conserved.

A 16

Measuring microwave stray radiation in the W7-X stellarator

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In magnetic fusion devices such as tokamaks and stellarators a common heating scheme is Electron Cyclotron Resonance Heating. High power microwaves are launched into the plasma and absorbed at the Electron Cyclotron Resonance. Depending on plasma conditions not all power is absorbed and after multiple reflections a stray radiation field results in the vessel, potentially damaging in-vessel components and diagnostics. Both for understanding of the physics and for protection, the stray radiation field must be monitored. However, obtaining fast, stable, and calibrated measurements is a challenge due to the constantly changing field pattern of the stray radiation. The poster explains the origin of the stray radiation by assessment of the power balance in a resonator. The inherent problems with standing waves caused by a monochromatic source is shown. A set of diagnostics is presented that - when combined - allow fast detection of RF-power for protection purposes while also providing stable and calibrated signals.

A 17

Waves in Plasma: Analysis of Dispersion Relation for High Frequency Waves in a Cold Magnetized Plasma

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To entirely control a plasma in a fusion reactor, scientist need to fully understand its properties. Electromagnetic waves are extensively used to both diagnose and control the plasma and The waves in plasma experiment , being a non-intrusive method, is an educational experiment to study wave propagation and allows to extract the plasma density without interfere with it.

From the theory of waves propagation, using the Appleton-Hartree equation, we obtain the formula for the refractive index. The index of refraction for the propagation of a wave in a plasma depends on the local plasma density, the background magnetic field, the angle between this one and the wave vector, and the frequency of the waves. Laboratory experiments that verify the propagation and damping of eletromagnetic waves in plasma, with waves propagation parallel to the external magnetic field, have been done. Fixing the background magnetic field at 51.3 mT and launching high frequency waves, f=1.296 GHz, with a Match-Zender interferometer and a oscilloscope for the phase-shift measurement, we obtain the refractive index of the plasma. The theoretical value of the plasma density is in good agreement with the laboratory data.

A 18

Plasma Assisted CO_2 reduction for synthetic fuels

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We explore a novel plasma processing method to produce CO, the most important ingredient in synthetic fuel production, from green house gas carbon dioxide (CO_2). This method also addresses the problem of increasing green house gas emissions along with the problem of finding viable methods to produce chemical feed stocks.

The formation of CO from CO_2 as a precursor is considered to be the most important step [1,2] in further fuel forming reactions. The present work explores the efficiency of CO_2 dissociation to CO in a low pressure plasma expansion, produced from mixtures of Ar and H_2 to which CO_2 is added in the background. Quadruple mass spectrometry (QMS) and mid-infrared tuneable diode laser absorption spectroscopy were used to measure the densities of various species formed.The effect of surfaces on the chemistry is studied by covering the reactor walls with various metal foils.

In Argon rich conditions, where the chemistry is mainly driven by charge exchange with Ar ions followed by dissociative recombination of CO_2^+, a CO yield of up to 50% is achieved. It is observed that copper surface plays a different role as compared to stainless steel or aluminum surfaces. In general CH_4 formation was detected at high hydrogen admixtures. C_2H_y hydrocarbons were in most cases absent while H_2O and CO turned out to be the main stable products. The results suggest an inherent syngas step during the plasma-assisted conversion approach.

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A 19

The Energy Balance of Hg-free HID lamps and the influence of electrode distance

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High intensity discharge lamps (HID lamps) are used when compact light sources are needed with high output levels and efficacies. The awareness of environmental issues related to mercury is becoming increasingly important. Therefore the focus of light source research has been shifting towards mercury-free light sources for general lighting.

We have determined the energy balance of several mercury free HID lamps with different electrode distances. We will show the influence of electrode distance on the efficacy of these mercury free HID lamps and that an optimal length exists.

The energy balance is a representation of the distribution of the total output energy of the lamp over different spectral regions and energy types, combined with a schematic overview of the different processes causing this energy distribution.

To determine the energy balance we have built an absolute calibrated integrating sphere setup. With this setup we are able to measure the complete light output of the HID lamp with a high spectral resolution. We cover the spectral range 200 to 10000nm. To distinguish between plasma radiation and thermal lamp wall radiation we perform a time dependant measurement after switching-off the HID lamp. We will show high resolution lamp spectra and discuss the spectral features we see. We will also show how the energy balance can be constructed from the integrating sphere spectrum.

A 20

Carbon Transport and Escape Fraction in a High Density Plasma Beam

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The lifetime of a carbon divertor facing ITER-like plasma conditions is limited by chemical erosion of the target plates and tritium retention due to co-deposition. If carbon re-deposition were to occur close to the site of erosion, rather than in remote areas, these problems could be mitigated. To investigate this possibility, the 3D Monte Carlo impurity transport code ERO was used to simulate methane injection experiments in the high-n_e linear plasma generator Pilot-PSI.

Methane was injected into the center of hydrogen plasmas, through a hole in a metallic (Mo) target. Typical conditions were $T_e \sim 1$ eV, $n_e \sim 10^{20}$ m^{-3} at the plasma axis, 12 mm beam width, and B = 0.4 T. In these conditions, hydrocarbon molecules ionize very efficiently due to charge exchange with H^+. Additionally, the Coulomb friction that causes transport back to the target due is very efficient at high densities. Because of this, the simulated fraction of carbon returning to the target typically goes up from approximately 75% at n_e=10^{20} m^{-3} to more than 99% at n_e=10^{21} m^{-3}. Experimental net redeposition values are lower than that, due to the strong erosion. The erosion yield was estimated by fitting experimental and simulated results. The results stress the beneficial role of a high electron density for establishing high local re-deposition.

A 21

Finite Difference Schemes for Anisotropic Diffusion

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In magnetically confined fusion plasmas there is extreme anisotropy due to the high temperature and large magnetic field strength to the extent that thermal conductivity coefficients can be up to 10^{12} times larger in the parallel direction than in the perpendicular direction. This anisotropy puts stringent requirements on the numerical methods. A common approach uses field aligned coordinates but in case of magnetic x-points and reconnection local non-alignment is unavoidable. Accuracy in case of high levels of anisotropy for non-field aligned grids is needed for the simulation of instabilities and radial transport processes in the presence of magnetic reconnection, e.g. with edge turbulence.

We therefore consider numerical schemes which are suitable for non-aligned grids. A novel method, developed to take into account the direction of the magnetic field, has been applied to the unsteady anisotropic heat diffusion equation on a non-field-aligned grid and compared with several other discretisation schemes, including Günter et al's symmetric scheme. Test cases include variable diffusion coefficients with anisotropy values up to 10^{12}, and field line bending in divergence and non-divergence free (unit vector) field configurations.

A 22

Breakdown processes in a gas discharge

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The initial stages of breakdown processes in an argon discharge are investigated with a time dependent multi fluid model – the PLASIMO's submodule called MD2D. The model is used to simulate the breakdown of a high-pressure argon-mercury filled HID lamp under different discharge conditions.

Special attention is paid to the transport and reaction rate coefficients which are required as input data for the fluid model. These coefficients are calculated externally using the freeware Boltzmann solver BOLSIG+ calculating the electron energy distribution function (EEDF) at a given value of the reduced electric field.

For the calculation of the EEDF the density of the excited species has to be provided, and for this purpose a collisional radiative model (CRM) has been constructed. Traditional CRMs use the electron density and electron temperature as parameters to calculate the specie densities. But in this case a CRM was constructed that calculates the specie densities as a function of the reduced electric field.

The breakdown voltage of an HID calculated with the fluid model is compared to experimental data and good agreement is found for different discharge conditions.

A 23

The effect of particle recombination in subsonic expanding Argon plasmas

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In the past decades, many studies have been performed that focus on the processes of charged particles in expanding thermal Argon plasmas. The reason is the large influence of these processes on characteristic plasma quantities like electron temperature and electron density and possible surface reactions, which in turn rules plasma assisted atomic depositions. Consequently, the aim of the research is revealing which processes rule the behavior of charged particles in this subsonic expanding Argon plasma. Measurements of the electron density obtained using a high quality Thomson-Rayleigh scattering diagnostic indicate that three body recombination of Argon plays a significant role in the subsonic area. Therefore insight in the development of the electron temperature and density is required. By consequence, the electron continuity equation and the electron energy equation including ambipolar diffusion and three body recombination of Argon will be analytically solved with suitable boundary conditions in axial symmetric coordinates. For simplicity, axial diffusion will be neglected. Besides, the axial and radial electron drift velocities have the same order of magnitude. The results of the analytic solution have been compared with the high quality Thomson-Rayleigh scattering diagnostic measurements. The analytic solution fits well with the measurements. From the results obtained it has been concluded that both diffusion and three body recombination of Argon are the most important processes ruling the temperature and density development in the subsonic part of the expanding thermal Argon plasma.

A 24

Dust particle formation in argon-acetylene plasmas and interaction with (extreme) ultraviolet radiation

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In extreme ultraviolet (EUV) lithography, ionic and particulate debris coming from the plasma source plays an important role. We started up a project looking more fundamentally at particulate formation in plasmas and the interaction with EUV radiation. To this end, we study a capacitively-coupled radio-frequency (13.56 MHz) argon-acetylene plasma.

In low-pressure hydrocarbon plasmas dust particles spontaneously form under certain conditions. The whole process occurs in a matter of seconds to minutes after igniting the plasma and results in a cloud of particulates up to micrometer sizes levitating in the plasma.

Our aluminum cylindrical discharge chamber also serves as a resonant cavity for low-power microwave (2 – 8 GHz) signals. The frequency at which resonance occurs is a measure for the free-electron density of the plasma.

We present preliminary results on the temporal evolution of the electron density during dust particle formation up to several minutes after plasma ignition. Furthermore, we present an overview of approaches for future research predominantly aimed at the interactions in a more EUV-like environment.

A 25

Pilot-PSI simulations using the coupled B2.5-Eunomia code

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The Pilot-PSI and Magnum-PSI plasmas are strongly influenced by the neutral particles. The charged species are simulated with the multi-fluid equilibrium code B2.5, part of the SOLPS code package. The neutral particles are in the regime where Navier-Stokes is invalid. Therefore, we developed Eunomia, a non-linear parallel kinetic Monte-Carlo code to simulate the neutral particles.

Eunomia calculates the density, temperature and background flow of the ground state atoms and all vibrationally excited molecules of hydrogen. A collisional radiative model accounts for the excited states of the hydrogen atom.

The strong interaction between the plasma and the neutral species requires a self-consistent coupling of B2.5-Eunomia. B2.5 provides Eunomia with a plasma background and Eunomia returns particle, momentum and heat sources and sinks to B2.5. We present first simulations of Pilot-PSI plasma beams, showing the large influence of molecular hydrogen.

B 1

Decontamination of burn wounds using a cold atmospheric pressure plasma jet

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In the treatment of burn wounds bacterial infections are a common problem. Next to conventional treatments, atmospheric pressure plasmas might be able to provide additional means to reduce the bacterial concentration in a burn wound.

In this work the effects of an argon atmospheric pressure plasma jet on both the gram negative bacterium pseudomonas aeruginosa and human keratinocytes and fibroblasts are investigated. Pseudomonas aeruginosa is a common cause of infection in burn wound patients. Keratinocytes are the predominant cells in the epidermis and fibroblasts are critical for wound healing. The influence of discharge power, duty cycle, treatment time and the addition of air on the survivability of the bacteria and cells is determined for two different electrode geometries. To be able to directly treat tissue the gas temperature has to be near room temperature and the UV production has to be limited. The gas temperature in the plasma as well as outside the plasma is estimated from the rotational temperature of the rotational bands of OH(A-X) and N_2(C-B) and thermocouple measurements respectively. Also the relative UV generated by the plasma is measured.

B 2

Stability study of high harmonic generation in a capillary for seeding of free-electron lasers

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The Free-Electron Laser (FEL) is the brightest X-ray source to date generating coherent radiation with gigaWatt peak power in femtosecond long pulses at a wavelength down to only a few angstroms. The FEL has made a breakthrough possible in ultrafast science by becoming an essential tool for applications such as coherent diffraction imaging of single molecules, femtosecond pump-probe spectroscopy and ultrafast chemical processes.

Because there are no suitable laser mirrors in the x-ray wavelength regime for feedback, many FELs in this regime are operating as a single pass system producing self-amplified spontaneous-emission (SASE). The amplification starts from the spontaneous radiation from electrons that not only produces fluctuations in the output pulse intensity but also limits its longitudinal coherence. To improve the stability of the output and in particular the longitudinal coherence required for many ultrafast applications, seeding by external sources has been proposed.

Here, we study the beam characteristics of a gas-filled capillary based high-harmonic source for seeding of the free-electron laser FERMI@Elettra. The stability requirements for seeding include pointing stability, divergence and energy jitter. These parameters are important due to the large distance between the source and the undulator where the seed needs to overlap with the electrons. High-harmonic generation (HHG) in a gas-filled capillary has several advantages over gas jet and gas cell. It is the only source that has demonstrated wavelength selective enhancement of a single harmonic by adaptive shaping of the drive pulse. Furthermore, the highest conversion efficiency in HHG has been shown using a capillary.

We will present the beam properties of high-order harmonics generated in a Xenon-filled capillary, driven by a Ti:Sapphire laser with 35 fs pulses. We will compare our experimental results with the requirements of the FERMI@Elettra FEL.

B 3

Oxidative degradation of toluene and limonene in air by pulsed corona technology

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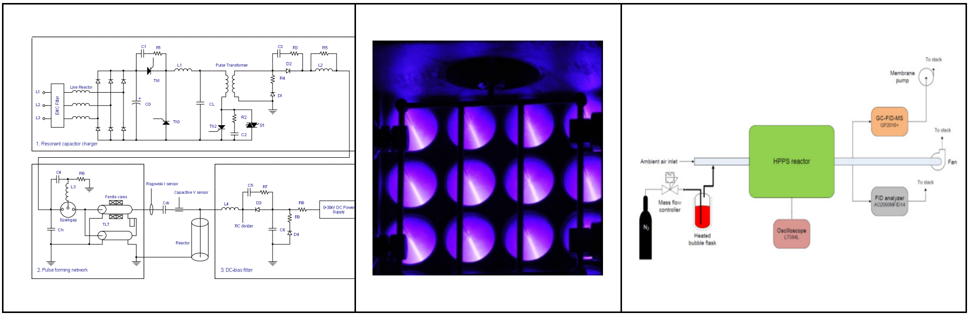
The oxidative degradation of two volatile organic compounds i.e. toluene and limonene, by pulsed electrical discharges, has been studied. The TU/e-EES 10 kW hybrid pulsed power corona reactor with adjustable energy density has been utilized for degradation of ppm-level target compounds in 150 m^3/h air flows. Degradation of the VOCs proceeds via reactive oxygen species like e.g. OH(X ^{2}□), O(^{3}P, ^{1}D, ^{1}S), O_2(a ^{1}□$_g$), O_3(X ^{1}A) and excited, metastable and/or ionized bulk gas species produced in the atmospheric plasma.



The oxidation product range, observed with gas chromatography-mass spectrometry, features a complex energy density-dependent spectrum of oxygen-functional hydrocarbons, which has been extensively discussed on the basis of literature studies. Typically observed stable oxidation products for both target compounds are the biocompatible carboxylic acids acetic and formic acid. Measured degradation efficiency G-values are 23 nmol/J at 74% conversion of 70 ppm toluene and 181 nmol/J at 81% conversion of 10 ppm limonene.

B 4

Electrical and Optical Diagnostics of an RF and a Nanosecond Pulsed DC Cold Atmospheric Pressure Plasma Jet for Biomedical Applications

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Plasma medicine is a research field that focuses on the biomedical applications of plasmas, such as disinfection and stimulating healing of wounds by plasmas. The goal is to reach a high bacteria killing rate, without damaging the skin. This limits the plasma sources in terms of heat dissipation, UV-emission and production of reactive species, while the latter two are also beneficial for wound treatment, at the right dose. Plasmas that can be used for this application are cold atmospheric pressure plasma jets which operate in noble gases with small admixtures of molecular gases. There exist a large range of different jets which usually differ in terms of excitation frequency, electrode configuration and gas composition. A direct comparison in terms of efficiency and plasma output of the different jets however is quite challenging.

In this contribution a self-made plasma jet operated either by continuous RF, kHz pulsed RF or nanosecond pulsed DC excitation in argon or helium is investigated. We discuss the main differences of power dissipation, gas temperature and influence of the plasma interaction with the bio-sample (saline solution) in terms of the discharge morphology and plasma propagation in the pulsed cases.

B 5

High-speed photography of long laboratory sparks

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We represent first detailed high-speed photographic observations of the long laboratory spark development process in our laboratory. Pictures obtained simultaneously with voltage, currents and X-rays measurements. Earlier, we showed that near-cathode area are responsible for X-ray generation during discharge development. Signal from X-ray detectors was registered in a good coincidence with high frequency cathode current oscillations in case of positive and jumps in case of negative discharges. Also, we obtained spectra of the X-ray emission. On this base, we made several assumption concerning the energy composition and nature of the X-rays, emitted from the long laboratory sparks and atmospheric discharges at all.

In this work we used a fast Picos4 camera with exposure time down to 200ps. We obtained the pictures of near-cathode area and full-length sparks up to 1.5 meter. Pictures of positive and negative corona, streamer/leader processes and other poorly investigated phenomena are represented.

B 6

Towards understanding terrestrial gamma-ray flashes (TGFs), hard x-rays and positron production in thunderclouds

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Thunderstorms generate Terrestrial Gamma-ray Flashes (TGFs) and even large amounts of electron-positron pairs. Electrons can gain energies of up to hundred(s) of MeV within thunderclouds. The calculation of X-ray and gamma-ray emissions from fast electrons in air requires appropriate differential cross-sections for the Bremsstrahlung generated when an electron collides with a molecule. Based on the quadruply differential cross section for Bremsstrahlung by Bethe and Heitler, we analytically calculated doubly differential cross sections that determine a distribution of photon emission angles for given electron and photon energy. Beyond that we make statements about the most probable scattering angle and extend our formulas for creating positrons in pair production processes.

B 7

High order fluid model for ionization fronts in streamer discharges

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When non-ionized or lowly ionized matter is exposed to high electric fields, non-equilibrium ionization processes, so-called discharges, can develop. Streamers occur in nature and as well in many industrial applications such as the treatment of exhaust gasses, polluted water or biogas. A third order hydrodynamic model is developed for the streamer dynamics by closing the system after the 4th moment of the Boltzmann equation. The transport and reaction coefficients for the model were obtained by solving a multi-term Boltzmann equation. The electric field generated by spaces charge is calculated with the Poisson equation. The high order pressure tensor appearing in the heat flux equation is specified in terms of previous moments. Simulations of the negative streamer planar ionization fronts in nitrogen are performed both with the classical so-called "minimal model", where the local field approximation is used, and with the present higher order model. The results are compared and conclusions on future simulation approaches are drawn.

B 8

OH radical density measurements in a cold RF atmospheric pressure plasma jet

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Cold atmospheric pressure plasma jets are used in a variety of applications such as surface modification, wound healing and disinfection. Hydroxyl radicals (OH) can be efficiently produced in non-equilibrium plasmas which either contain water or interact with humid air. OH is a highly reactive species which can easiliy oxidize organic molecules. Therefore, it can greatly influence surface functionalization and it is an active component in disinfection of surfaces and wounds.

In this contribution, the production of the OH radical is investigated in the commercially available RF atmospheric pressure plasma jet kINPen 09, which is developed at the INP in Greifswald. Both optical emission spectroscopy (OES) and laser induced fluorescence (LIF) is applied to obtain an estimate of the relative and absolute OH density in the effluent of the Ar plasma jet. The relative OH emission intensity is acquired by spatially resolved OES measurements along the length of the plasma jet for various partial water pressures. The OH emission intensity exhibits a maximum at 1000 ppm and rapidly decreases for higher partial water pressure. After corrections made for the decrease in emission by quenching of the OH(A) state by water, the corrected OH emission intensity increases for higher water concentrations. LIF measurements which probe directly the ground state density of OH show the same water concentration dependence as the quenching corrected emission intensity. Additionally, absolute OH densities are determined by a LIF model based on a calibration with Rayleigh scattering.

B 9

In-situ mapping of 3D material flux in PLD plasmas

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Pulsed Laser Deposition (PLD) has been established in recent years as a very versatile deposition technique for complex materials. Much empirical research has been done to determine the perfect recipe – settings of deposition parameters like background gas and pressure, laser fluency, etc. – for a successful growth of thin films with atomic precision.

However, such precise deposition of thin films is still limited to approximately 1cm^2. To scale PLD to full wafer size, a more fundamental understanding of the material flux in the plasma plume is required, since composition, speed and direction of material strongly influence the film growth.

We are currently building a PLD system in which we incorporate three spectroscopic techniques. Combining Laser Induced Fluorescence imaging, Absorption Spectroscopy and Doppler Shift measurements, we can generate a 3D map of the material flux. This information will provide insight in the relation between the deposition parameters and the film growth.

B 10
The influence of laser parameters in Pulsed Laser Deposition thin film growth

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PLD has been established in recent years as a very versatile deposition technique for complex materials, including complex oxides. PLD utilizes the transient particle flows of a laser-induced plasma to achieve a fully controlled (also crystalline) growth of thin films.

Considering the growth process at the substrate surface, involving plasma substrate interaction, particle diffusion, nucleation and the formation of perovskite structured crystal lattices, knowledge is limited. Only the final results of these processes, the grown film, is usually characterised. Clearly, laser parameters influence the plasma, the kinetic growth characteristics and stoichiometry of the film. Therefore, the stoichiometry of the plasma and the grown film are obviously related, but the relation between plasma composition, and surface diffusion and 'sticking' of particles, is unclear. The knowledge of the influence of various PLD growth parameters, such as laser intensity, pressure and temperature is of empirical nature.

This research focuses on understanding the influence of laser fluency and oxygen background gas pressure on plasma composition and thin film growth of perovskite oxides. For this purpose, different material systems are selected and which show significant influence of the fluency on their stoichiometry, which in turn is an important parameter for its properties, i.e. electrical transport.

The material system presented here is $SrTiO_3$ (100) films grown on $SrTiO_3$(100). Stoichiometry of $SrTiO_3$ on $SrTiO_3$ thin film is determined by X-ray scattering, were a clear oxygen pressure and fluence dependence on the film stoichiometry is shown, partially in accordance with Ohnishi, (APL 87, 241919, (2005)).

This project is part of the perspective Building on Transient Plasmas (BTP), STW proposal 10760.

B 11

Towards user-friendly, public domain streamer discharge simulation software

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Streamers are rapidly growing plasma filaments that can penetrate into non-ionized regions due to the electric field enhancement at their tips. They play an important role in creating the paths of sparks and lightning in nature, and are also widely used in industrial applications.

In past years, a number of computer simulation codes for streamer discharges have been developed by our group at CWI, using Particle-in-cell/Monte Carlo, fluid and hybrid codes from 1D to 3D. Adaptive grid refinement and parallelization techniques are also adopted. Our codes have the ability of modeling problems in plasma-technology, in high voltage engineering as well as in lightning-related processes. However, a few shortcomings of the codes also exist at this moment, because they were written by different members; some codes are difficult to understand and to reutilize due to their weak annotation. The goal of current work is to co-develop and improve streamer discharge simulation software in our group, in particular, optimizing and documenting the codes in detail. The codes will be made available on internet as freeware for academic and industrial users.

B 12

Particle based 3D modelling of streamer discharge inception

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Streamers are thin conducting plasma channels surrounded by a space charge layer that propagate at a high velocity. Experimental observations have provided more insight in their formation near positive electrodes, showing a growing 'inception cloud' that destabilizes into one or more streamers. Several fundamental questions arise: When does such a cloud form and when does it destabilize into streamers? And what is the electron energy distribution during inception? To answer these questions we have developed a particle based 3D simulation of the streamer inception process near positive electrodes. We discuss the model choice, present simulation results and indicate possible improvements.

B 13

Boosting the recovery rate of plasma switches by application of a supercritical state liquid as switching medium

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The electrical breakdown phenomenon of an air-blown plasma switch with pressure up to 5 bar compared with a supercritical plasma switch with pressure up to 100 bar are presented, focusing on the breakdown time delay and breakdown voltage variation corresponding to the voltage repetition rate, gap width and gas flow rate through the gap. A new design for a versatile high-power supercritical media plasma switch with pressure up to 200 bar is explained. Integrated charging capacitor, adjustable heavy duty electrodes, and imbedded current and voltage sensor ensure the multiformity and flexibility of the supercritical media plasma switch.

B 14

Direct synthesis of Hydrogen Peroxide in the gas phase using ambient pressure Microplasmas

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Hydrogen peroxide (H_2O_2) is an important chemical compound in industry and is used in a wide array of applications. This work has the goal to use H_2O_2 produced by an ambient pressure microplasma in-situ for the epoxidation of propene to propene oxide, a major bulk material in the chemical industry. In contrast to established methods in industry, this approach can improve the overall cost-effectiveness of the production process and is especially more safe for explosive gas mixtures.

The H_2O_2 production yield in a parallel plate capacitive coupled RF discharge and a dielectric barrier discharge (DBD), both operating at ambient pressures and close to room temperatures have been investigated using different gas mixtures (humid Helium and H_2/O_2 mixtures with Helium). In the course of the planned work we aim to understand the requirements of an efficient and stable low temperature gas discharge for producing hydrogen peroxide from either water or hydrogen oxygen mixtures (potentially with added inert gases). As H_2O_2 easily dissociates thermally it is essential to work close to room temperature. In this contribution we will discuss the dependency of OH production on different plasma conditions in the DBD and capacitive coupled RF discharge.

B 15

Measuring the ozone concentration in the effluent of an APPJ by UV absorption spectroscopy

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Cold atmospheric pressure plasma jets (APPJs) are promising tools for biomedical applications. APPJs can operate close to room temperature and open to air at atmospheric pressure. They can also be safely touched. APPJs produce a highly reactive plasma cocktail consisting of radicals and oxidizing species such as OH, O, NO, O_3, in addition to excited species, ions and UV radiation. As many of these constituents enable plasma to sterilize and disinfect, it is important to study the chemical and physical process of the plasma jet including the concentrations of these radicals in order to understand the plasma effect on biological samples.

Of all the oxidizing species produced by APPJs, O_3 is a strong oxidizer, has a long life time and is used on its own in disinfection applications. In this contribution, we present UV absorption measurement of absolute concentrations of ozone in the effluent of the atmospheric pressure plasma jet.

The APPJ used in this study is produced by a RF excited DBD-like source in Ar-O_2 gas mixtures which are blown through the discharge area. The O_3 concentration is measured in the effluent of the plasma, which is open to air, at the location where the treatments are made. The size of the effluent, so the absorption path length of O_3, is of the order of 2mm which provides several challenges to measure the O_3 concentration accurately. This will be discussed in detail in this contribution.

B 16

Extreme ultraviolet source based on high harmonic generation from ions for the direct seeding of Free Electron Lasers

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Fermi@Elettra is a Free-Electron Laser (FEL) that uses high-gain harmonic generation (HGHG) to produce stable and fully coherent XUV light pulses down to a wavelength of 20 nm (FEL1). A cascaded set-up, where the output of the first HGHG section will be used to seed a second HGHG section, is required to realize seeded operation for wavelengths as short as 4 nm (FEL2).

As an alternative to such a cascaded HGHG setup, we investigate the possibility of direct seeding (down to 4 nm) using a bright, coherent XUV source based on high harmonic generation (HHG) from ions. The reason to use ions instead of neutral gases is their higher ionization potential such that a much shorter cut-off wavelength can be realized in the harmonic generation process. However, due to the higher ionization degree of the harmonic medium in comparison to neutral gases, current phase-matching techniques applied to HHG in neutral gases are not suitable. Instead, we will investigate quasi phase matching (QPM) and waveguiding over an extended interaction length to provide the necessary seeding energy. For this, we prepare a plasma waveguide for the drive laser with an appropriate density modulation along its axis for QPM.

We present the set-up for HHG which includes a density modulated cluster-jet, a high energy, pico-second Nd:YLF laser system for the generation of the plasma waveguide in the modulated cluster-jet, and a femto-second Ti:Sa drive laser system for the harmonic generation. The generation of the high energy laser pulses from the Nd:YLF laser system, and the synchronization between the Nd:YLF and Ti:Sa laser system will be discussed in detail. To determine the smallest possible period for QPM, we will use Rayleigh scattering and interferometry to characterize the modulated cluster jet. These diagnostic techniques will also be presented.

B 17

Reduced bandwidths for soft-x ray reflection using Lamellar Multilayer Gratings

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Lamellar Multilayer Gratings (LMG) offer reduced bandwidths for soft-x-ray (SXR) reflection, while maintaining a high reflection efficiency in comparison to conventional multilayer mirrors (MM). A Coupled-Waves Approach (CWA) was used to calculate SXR diffraction by LMGs. From this CWA, a single-order regime was identified in which the incident wave only excites a single diffraction order. It was shown that in this regime the angular width of the zeroth-order diffraction peak simply scales with Γ (lamel-to-period ratio) without loss of peak reflectivity. To obtain maximal peak reflectivity the number of bi-layers must be increased by a factor of 1/Γ. Optimal LMG bandwidths and reflectivities are obtained in this single-order regime, requiring grating periods of only a few hundred nm, lamel widths < 100 nm and lamel heights > 1μm [1].

For the fabrication of LMGs with these dimensions, a novel process based on UV-NanoImprint Lithography (UV-NIL) and modified Bosch etching is used. Successful fabrication of LMGs with periods down to 200 nm, line widths of 60 nm and multilayer stack heights of 1μm is demonstrated. SXR reflectivity measurements have been performed on these LMGs at the PTB beamline at the BESSYII synchrotron facility. The bandwidth is demonstrated to be reduced by a factor of 4 compared to conventional MM. Further analysis of these SXR reflectivity measurements is currently being performed.

[1] I.V. Kozhevnikov, R. van der Meer, H.M.J. Bastiaens, K.-J. Boller and F. Bijkerk, Opt. Exp. 18, 16234 (2010).

B 18

An Ultracold Electron Source for Ultrafast Electron Diffraction Experiments

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We report on the development of a pulsed electron source that produces ultrashort, ultracold electron bunches. These bunches are made by accelerating electrons which are created by near-threshold photoionization of a cloud of laser-cooled atoms.

The electron bunches that are created from this source will be used to perform single-shot, ultrafast electron diffraction (UED) experiments on crystals of macromolecules, such as proteins, which is not possible with the conventional photocathode source. This opens the possibility to study the structural dynamics of macromolecules with both spatial and temporal resolution at the atomic level (i.e. 0.1 nm and 0.1 ps).

To ensure high quality diffraction data, the electron bunches should be sufficiently coherent, with a transverse coherence length of at least a few lattice spacings of the crystal under investigation. For protein crystals, the lattice spacing ranges from a few nm to a few tens of nm.

Here we will show our recent experimental results in making ultrashort, ultracold electron bunches, with temperatures as low as 5 K and an expected pulse length in the order of picoseconds. Such low temperatures lead to an electron bunch with a transverse coherence length of around 100 nm at a spot size of 200 μm, or equivalently 1 nm at 2 μm spot size. This amply fulfills the coherence length requirement for diffraction experiments.

B 19

The Balmer line radiation of Pilot-PSI modeled with a collisional radiative model

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The atomic hydrogen density in the plasma beam of Pilot-PSI not only originates from three-body and radiative recombination, but also from dissociative recombination of molecular hydrogen ions. This molecule assisted recombination (MAR) is initiated by charge exchange between a proton and a vibrationally excited hydrogen molecule. Another process involving vibrationally excited molecules is dissociative electron attachment, leading to negative ions that are readily neutralized in collisions with a proton. All processes involving excited molecules lead to the generation of excited atomic hydrogen, emitting a.o. Balmer line radiation. With a collisional radiative model that includes the above mentioned processes and reabsorption of the Lyman-alpha and beta lines we have analyzed the origin of the Balmer line radiation in the Pilot-PSI plasma beam. Densities of the ground state atoms and all vibrationally excited molecules are provided by Eunomia, a Monte Carlo kinetic code for neutral species. Eunomia calculates these densities for electron temperature and density profiles obtained from Thomson Scattering. Comparison of the simulation results to experimental data showed that the vibrational state distribution of molecules formed at the walls is a crucial parameter. A sufficient amount of excited molecules is needed to match the experimental results.

B 20

Surface Discharges on Glass and Strontium-Titanate

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Surface discharges are investigated to be used as high power, low inductance switches for nanosecond high-voltage pulse applications. When a high-voltage pulse is applied to one of the electrodes on the surface of the dielectric, a plasma starts to develop on the dielectric surface. After the plasma reaches the second electrode, a currents starts to run, further changing the plasma appearance and properties. To create the desired electrical characteristics of the switch, the formation of the plasma needs to be controlled. To study the growth phase of the plasma, optical imaging is performed. Two images of the plasma are made on a single camera. The time delay between the two images can be accurately controlled and is set to 500 ps. Comparing each set of images gives the growth speed during the initial plasma formation. Four *D-dot* probes are placed in the ground plane underneath the dielectric to follow the potential on the surface of the dielectric in time.

The surface discharge switch is operated with glass as the dielectric and with three different gases (air, argon and helium) at pressures between 100 and 1000 mbar. The growth speed of the plasma depends on the pressure and on the gas composition. The 'structure' of the plasma is also influenced by the gas composition and pressure. This 'structure' can already be recognized in the initial development of the plasma, before it reaches the second electrode.

For the desired electrical properties, specifically a fast risetime, it is presumed that the plasma needs to grow slowly, so that the front of the plasma stays at the same potential as the electrode. A simple lumped element model is used to illustrate this. To reduce the growth speed of the plasma, Strontium-Titanate is used as the dielectric. The $SrTiO_3$ substrate used has a relative dielectric constant of 100. The results show that the growth speed is indeed reduced (from 2×10^6 to 0.5×10^6 m/s at 1000 mbar air). The images taken of the initial growth phase of the plasma, again show very nicely the different structures arising in the plasma under different conditions.

B 21

Laser based diagnostics at Magnum-PSI

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Multiple diagnostics based on lasers are in use at Magnum-PSI. The linear plasma generator simulates plasma-wall loads typical for the ITER divertor: continuous 10 MW/m^2 and transient 1 GW/m^2. An advanced Thomson Scattering (TS) system has been built, based on a Nd:YAG laser (532 nm) and a transmission grating spectrometer. The TS system measures electron density (n_e), temperature (T_e) and neutral density (n_0) profiles of a 100 mm diameter plasma column close to the output of the plasma source and close to the target (1.2 m from the plasma source). Very low n_e (9×10^{18} m^{-3}) can be measured within seconds with an accuracy as low as 3%. The minimum measurable density and temperature are $n_e < 1\times10^{17}$ m^{-3} and $T_e < 0.07$ eV, respectively. The TS system is fully operational and experimental results on magnetized plasmas will be shown. In a feasibility study it has been shown that collective TS can be applied at Magnum-PSI that enables to measure the ion temperature and plasma flow velocity with an accuracy of <8% and <15%, respectively. Surface diagnostics based on Laser Induced Desorption Spectroscopy (LIDS), Laser Induced Ablation Spectroscopy (LIAS) and Laser Induced Breakdown Spectroscopy (LIBS) are installed at Magnum-PSI for measuring deuterium (substitute for tritium) retention in plasma facing components. Using Magnum-PSI as a testbed, it needs to be determined whether or not these diagnostics can be applied in ITER to serve as monitor for the wall condition. These laser based surface diagnostics will be described along with first experimental results.

B 22

Modelling of a coaxial plasma line source

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In this study a microwave discharge (f = 2.45 GHz) in low pressure argon gas in a coaxial structure is investigated. The used geometry is advantageous for large area deposition. In this structure plasma acts as an outer conductor of a coaxial waveguide where the microwave power is consumed. That leads to a spatially extended propagating kind of surface wave.

In here a two dimensional fuid model of a coaxial plasma line is presesnted. The model was created using the Plasimo modelling platform and it describes s the electromagnetic and fluid aspects. The model is used to investigate the effect of control parameters on the structure and shape of an argon plasma..

B 23

Fluctuation dynamo driven by shear-bursts

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Intermittent high-shear flows are discovered to frequently and spontaneously occur in high resolution direct numerical simulations of steady-state Boussinesq MHD convection. The energetic steady-state of the system is sustained by convective driving of the velocity field and small-scale dynamo action. The intermittent emergence of large flow structures with strong velocity and magnetic shearing generate magnetic energy at an elevated rate over time-scales longer than the characteristic time of the large-scale convective motion.

B 24

Bifurcation to the H-mode

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Fusion energy production from magnetically confined plasmas strongly benefits from the spontaneous plasma transition to a state with double energy confinement called H-mode. The mechanism of this H-mode transition, involving suppression of plasma turbulence, is poorly understood: The range of available experimental tests does not fully discriminate between global characteristics of the many proposed models. Instead we use bifurcation theory to compare the highly nonlinear dynamics of H-mode models right at the transitions.

Bifurcations in a system of 1-dimensional diffusion equations[1] for density, temperature and the radial electric field near the plasma edge are studied.

The steady-state profiles satisfy a nonlinear boundary value problem for ODEs. We obtain a family of steady-state profiles parameterized by the total plasma heating power using the numerical continuation software Auto. First results show how the bifurcation diagram of the H-mode transition is influenced by the boundary conditions for the radial electric field at the plasma edge. The stability of the steady states is examined by simulating the full system of PDEs using as initial conditions perturbed equilibriums.

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B 25

Bifurcation theory for L-H transition dynamics in fusion plasmas

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Fusion energy production from hot magnetically confined plasmas came a step closer to realization with the discovery of a spontaneous plasma transition to a state with double energy confinement, the H-mode. The mechanism of this H-mode transition, suppression of plasma turbulence, is poorly understood: The limited range of available quantitative experimental tests cannot discriminate between the many proposed models. These models, however, must be able to describe the qualitative characteristics of the L-H transition, i.e. a unified description of sharp L-H and H-L transitions (exhibiting hysteresis) and the sometimes observed oscillatory transitions (i.e. 'Dithering H-mode'). Bifurcation theory requires that such models must contain a specific bifurcation of co-dimension 3. We identify such a bifurcation in continuous (1-D spatially extended) plasma models, one based on turbulence suppression due to flow and one due to flow shear. Hence both mechanisms may contribute to the bifurcating behaviour of the L-H transition.