SFB-TR 87

# NEWSLETTER

EDITION 4


## Edition 4/2017

## Foreword

### Annotations of the editorial office

The research progress within the last seven and half years is now in an advanced stadium, so that the request for extension of the successfully operating SFB-TR 87 is being in the final phase. The proposal for the funding of the final four years is now being send to the German Research Foundation. Furthermore, the on-site inspection is already dated for March 2018.

It has been shown in the last years that the cooperation between the different projects has developed very well. Also, the aspect of application and the newly embedded projects show that the SFB-TR 87 is now ready for the last, fourth funding phase to reach its predefined aim.

Recently, the German Research Foundation approved the Collaborative Research Center (CRC) 1316 with the title *Transient atmospheric plasmas – from plasmas to liquids to solids*, which is thematically disjunct from the SFB-TR 87. The spokesperson of the CRC 1316 is Prof. Achim von Keudell, also PI in the SFB-TR 87. The research focus is on the basic understanding of atmospheric pressure plasmas and its catalytic application. Several PIs from the SFB-TR 87 also join this new research project.

Therefore, it is reasonable to combine the public relations projects of the two research centers. Consequently, the work of the project public relations and, specifically, the next newsletter of the SFB-TR 87 will include more content and will be concerning the presented topics. Of course, the CRC 1316 will be presented and research aims will be discussed.

We are looking forward to the new newsletter which will be published in June, 2018.

## Farewell

### Thomas Mussenbrock

PI **Thomas Mussenbrock** became full professor (W3) at the Electrodynamics and Physical Electronics Group (EPEG) at the Brandenburg University of Technology Cottbus-Senftenberg. He was project leader of the project C8 as well as of the public relations project of the SFB-TR 87 for the last seven and half years. Staying with his expertise in the SFB, he continues his work in project C8 from his new workplace in Cottbus.

His research interests are in the area of electromagnetic fields as well as modeling and simulation of non-equilibrium systems with a focus on low temperature plasmas and ionic devices.

Continuing his work in Bochum, he is also visiting professor and supervisor of PhD students at the Ruhr-Universität Bochum.

## Tribute

### Jochen Schneider

**Prof. Jochen Schneider**, deputy spokesperson of the SFB-TR 87, was appointed Visiting Professor for Materials Chemistry and Materials Physics at the University of Uppsala, Sweden, in May. He is project leader of the project *Quantum-mechanically guided design of wear-resistant coatings for polymer moulding*. Congratulations to him!

# Probing the electron density in HiPIMS plasmas by target inserts

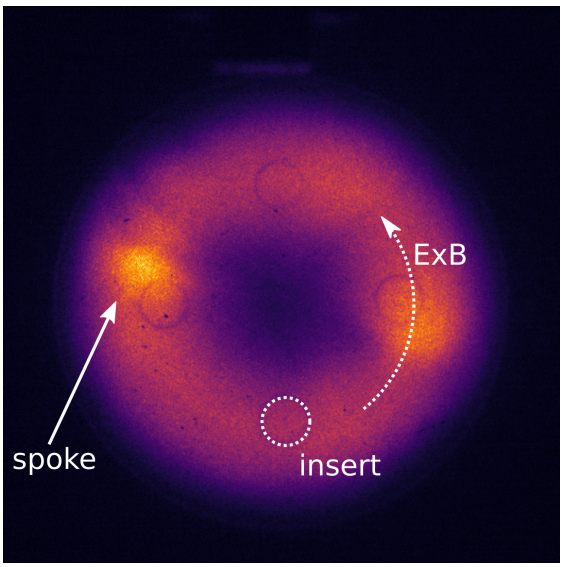


Figure 1: False color image of the discharge in front of the target. The 4 probes inside the target surface can be seen as dark outlines. Two spokes rotate in the marked direction.

The main focus of subproject A5 is the physics of high power pulsed magnetron sputtering (HiPIMS). A point of particular interest are the so called spokes. Spokes are zones of high optical emission, which rotate in front of the target. The spokes are thought to have a high internal electrical potential, and are therefore supposed to be used to promote transport of ions. For future applications, this might be the key to optimizing the deposition rate of HiPIMS.

The most important plasma parameter in understanding the spokes is the electron density. However, this parameter has long eluded plasma scientists, since the target region of HiPIMS is not accessible for the methods that are usually used to measure the electron density.

In a recent publication, Ante Hecimovic and his colleagues of the A5 project have made a huge step forward in measuring this important parameter.

The idea for this measurement is rather simple: small, electrically isolated inserts in the target surface are used as probes to measure the local current density. It is then possible to calculate the electron density at the edge of the plasma sheath in front of the target using simple sheath theory. The implementation of this, however, proved to be quite problematic. Since the plasma density in HiPIMS is very high, that kind of plasma can be ignited even in small gaps, like the gaps between the probes and the rest of the target material. It took over one year until scientists overcame the struggles and were able to ignite a stable discharge without any secondary plasmas. Success followed only after reducing the number of probes from 12 to 4 and after carefully reengineering the electrical isolation between the probes and the target material.

This work has paid off, and the desired results could finally be archived. The measurement of the electron density shows the expected oscillations when a spoke moves over one of the probes, as can bee seen in figure 2. The electron density is about 50 % higher, if a spoke is present. By varying the applied voltage, it was found that the electron density scales linearly with power density or discharge current, just as expected.

The article was published in the Journal of Physics D: Applied Physics by IOP Publishing under the title: *"Probing the electron density in HiPIMS plasmas by target inserts"*.

The paper additionally discusses the plasma sheath in front of the target. The sheath could be shown to be un-magnetized and collisionless, which is an important information for modeling the discharge.

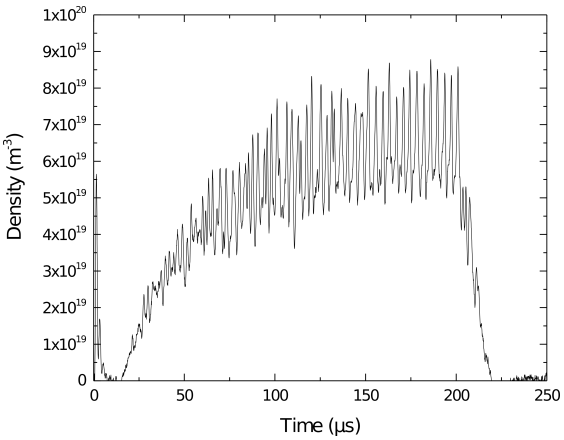


Figure 2: Evolution of the measured electron density during a single HiPIMS pulse. The oscillations are caused by the spokes moving over the probe.

**Tribute**

## Awards for SFB-TR 87 members & Finished PhD theses

**Lukas Mai** won the Award of the Ruhr-Universität Bochum for an excellent scientific thesis which has the title *Tuning precursor chemistry and development of Plasma-Enhanced Atomic Layer Deposition processes of aluminium oxide*. The annual price is given to selected students from all faculties who finished with an excellent thesis at the RUB. It is granted during the academic anniversary celebration at RUB.

**Sebastian Wilczek**, PhD student at the Institute for Theoretical Electrical Engineering (Ruhr-Universität Bochum) has been awarded with the Student Excellence Award at the Gaseous Electronics Conference (GEC) for his outstanding talk with the title *Differences between Cartesian and Spherical 1d3v Particle-In-Cell Simulations*. His talk focused on the control of electron dynamics in low pressure capacitive radio-frequency discharges. It showed that non-linear and non-local effects play a process-relevant role and can be more effectively controlled in both asymmetric and symmetrical radio-frequency discharges by selecting various process parameters (e.g. gap distance, excitation frequency). The results have revealed that electron dynamics on the time scale of nanoseconds must be understood.

**Manaswi Daksha**, student at RUB got a Poster Award at the Geseous Electronics Conference for his poster with the title *A real-time model for secondary electron emission coefficients in low temperature plasmas*. His contribution deals with one of the most important parameters in plasma surface interaction, the ion-induced secondary electron emission coefficient (SEEC). Manaswi Daksha has worked on a theoretical model for the determination of SEEC for different surfaces and process gases. His work actually fits into all areas of the SFB, since it provides an exact determination of the SEEC.

**Dr.-Ing. Tobias Brögelmann**, PI of the projects A1 and C6, won the GfT-award in the category 1 for dissertations of the Society for Tribology (GfT). The topic of his PhD thesis was *Friction reduction by graded carbon layers a-C:H:Zr and a-C:H:Ti in EHD contacts of the automotive powertrain*.
Congratulations!

## Finished PhD theses

We would like to congratulate two former PhD students from the SFB-TR 87 who succeeded their defense.

- **Dr.-Ing. Jan Trieschmann** obtained his PhD in May 2017 at the Institute for Theoretical Electrical Engineering at the Ruhr-Universität Bochum. His thesis was titled *Particle Transport in Technological Plasmas* and part of the C8 project. Congratulations!
- We would also like to congratulate **Dr. rer. nat. Marcus Hans** who obtained his PhD in September, 2017 at the Chair of Materials Chemistry at the RWTH Aachen University. His thesis *Metastable cubic transition metal aluminium nitride and oxynitride coatings: Theoretical phase stability and defect structure predictions and verification by industrial-scale growth experiments* was part of the project A3.

# Comprehensive cooperation on defects in permeation barrier coatings

Recently new results were published in the B section (dealing with the modification of plastics) of the SFB-TR 87. The work of Felix Mitschker and his colleagues clarifies the influence of the atomic oxygen fluence on defect formation in barrier coatings for polymers and, notably, comprising contributions of all projects in the B section of the SFB-TR 87. Additionally, a comparison between defect formation of different PE-CVD (plasma enhanced chemical vapor deposition) and PE-ALD (plasma enhanced atomic layer deposition) coatings is performed.

The background of this paper is based on the fact that polymers exhibit no significant gas barrier performance. However, this is an important requirement in many applications dominated by polymers, e.g. encapsulation of microelectronics and food packaging. A great variety of different inorganic coatings are applied by plasma assisted processes to achieve a barrier improvement by several orders of magnitude. Nevertheless, a residual permeation through plasma-deposited barrier films is present. Compared to diffusion through bulk silica of the same thickness, a plasma deposited silicon oxide film exhibits 13 orders of magnitude higher permeation rates. This is attributed to defects that are contained in such thin barrier films. Detection of such nanometer-sized defects in transparent barrier coatings is challenging, as they are not visible by optical or electron microscopy, usually. However, visualization is achieved by etching with reactive oxygen. Compared to inorganic materials like silica, organic polymers are sensitive towards etching with reactive oxygen like atomic oxygen. Atomic oxygen can enter defects in inorganic coatings and etch the underlying polymer, which results in an undercutting of the barrier layer underneath existing defects, like shown in figure 3. Subsequent imaging by scanning electron microscopy allows for the quantification of these defects. In combination with optical emission spectroscopy, the flux of atomic oxygen flux is quantified and, thus, the influence on defect formation during the deposition of silicon oxide films is revealed. In this regard, it is shown that a sufficient amount of oxygen atoms impinging on the surface during the process is beneficial for defect formation, as the defect density is significantly decreased. Additionally, this has a positive effect on the barrier performance.

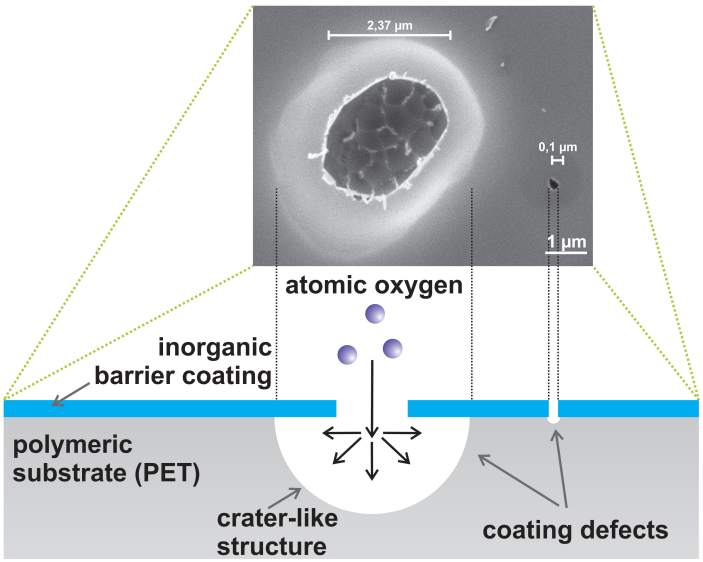


Figure 3: Schematic illustration of coating defect visualization by oxygen etching in a reactive plasma.

Furthermore, a comparison between diverse deposition techniques shows differences in defect formation. PE-ALD exhibit homogeneous and defect free coatings with a high barrier improvement. Relative to that, however, higher defect densities and, consequently, higher permeation rates are inherent to PE-CVD processes. This fortifies the idea that defects have to be avoided, when targeting a preferably high barrier performance. This comprehensive cooperation was established by advantageous contributions (thin film analysis, plasma diagnostics, coating processes, etc.) of all section B projects and linked the plasma parameters with thin film analysis in a novel and meaningful way.

The paper *Influence of PE-CVD and PE-ALD on defect formation in permeation barrier films on PET and correlation to atomic oxygen fluence* was published in the Journal of Physics D: Applied Physics, Volume **50** (2017), 235201.

## Plasma School

The scientific organization of the 21st Plasma school was realized by Olivier Guaitella and Anne Bourdon from Laboratoire de Physique des Plasmas, Ecole Polytechnique in Paris, France. The local organization team consisted of Achim von Keudell, Marc Böke, and Marina Prenzel from the SFB-TR 87. The Plasma school took place in the Physikzentrum in Bad Honnef. The aim of the school is to teach the students the basics and to present the status of research in low temperature plasma physics.

The students can interact with the teachers of the course and meet fellow students from other universities in Europe and the rest of the world.

Participants can present their research in one of the poster sessions and discuss their work with other students or teachers. The program is split into a basic part and a Master Class. The topic of the Master Class in this year was *plasma surface interaction*.

Many young researchers of the SFB-TR 87 participated in the School which was taught by experienced researchers to deepen their knowledge on plasma physics.

## Gaseous Electronics Conference

The 70th Gaseous Electronics Conference (GEC) in Pittsburgh, USA, was important for the SFB because many talks discussed research topics related to the work of the SFB. Consequently, a large delegation of RUB members joined this event having fruitful discussions with other researchers.

Especially, a highlight was the talk from Jon Tomas Gudmundsson about *The role of recycling in pulsed sputtering magnetrons*.

The PI Denis Eremin was an invited speaker with the topic *Particle-in cell simulation of instabilities in magnetron plasmas*.

## V 2017

The "V2017 - Industrieausstellung & Workshop-Woche" took place in the DGUV academy in Dresden from October 24th to 26th, 2017. It was hosted by the *Europäische Forschungsgesellschaft Dünne Schichten e.V.*

The SFB-TR 87 was represented with numerous presentations and a booth in the industrial section of the exhibition. The aim was to give visitors of academical and industrial institutions insight into the different research areas of the SFB. Additionally, the process to comprehend the various properties of coating plasmas from the gaseous phase up to power characteristics were depicted. The visitors could look through presentations about the individual projects with available iPads at the booth.

Furthermore, a few exhibits including snail extruders, voltage detectors, and a multipole resonance probe were displayed. For publicity purposes, SFB-TR 87 labeled coffee mugs and bags were distributed among spectators. Many interesting discussions raised up about the various research fields, applications, and the acquired knowledge within the SFB.

## About Novel Research Activities

### Investigation of the HPPMS process for improved tool coatings in plastics processing industry

Latest cooperations between the subprojects C6, A1, A5, and C2, resulted in the fundamental investigations of an industrial (Cr,Al)N reactive high power pulsed magnetron sputtering (HIPIMS) process at the Surface Engineering Institute (IOT) of RWTH Aachen University.

The results will be used to improve the coating development for tool coatings in the plastics processing industry. Based on a process window of A1, substrate-oriented plasma diagnostics and deposition of the (Cr,Al)N coatings were performed in an industrial coating unit CC800/9-Modell, CemeCon AG, Würselen, Germany, for a variation of the HPPMS pulse frequency with values from f = 300 Hz to f = 2,000 Hz at constant average power P = 2.5 kW and pulse length $t_{on}$ = 40 $\mu$s. The plasma was investigated using an oscilloscope (C6), intensified charge coupled device camera (ICCD, A5), phase-resolved optical emission spectroscopy (PROES, A5) and energy-resolved mass spectrometer (ERMS, C6). The coating properties were determined by means of scanning electron microscopy (SEM, C6), glow discharge optical emission spectroscopy (GDOES, C6), cantilever stress sensors ($\sigma$-sensors, C2), nanoindentation (C6) and synchrotron X-ray diffraction (XRD, C2). Regarding the plasma properties it was found that the average energy within the plasma is nearly constant for the frequency variation. In contrast, the metal to gas ion flux ratio is changed from $J_M/J_G$ = 0.51 to $J_M/J_G$ = 0.10 for increasing frequencies. Regarding the coating properties, a structure refinement as well as lower residual stresses, higher universal hardness and a changing crystal orientation from (111) to (200) were observed at higher frequencies. By correlating the plasma and coating properties, it can be concluded that the change in the gas ion to metal ion flux ratio results in a competitive crystal growth of the film which results in changing coating properties.

The results are published in the Journal of Applied Physics **122** (2017) 015302 by K. Bobzin, T. Brögelmann, N.C. Kruppe, M. Engels*, A. von Keudell, A. Hecimovic, A. Ludwig, D. Grochla, L. Banko, with the title *"Fundamental Study of an Industrial Reactive HPPMS (Cr,Al)N Process"*.

*corresponding author

## Upcoming Dates 2018

**March 4th - 9th**

DPG Spring Conference with the section Plasma Physics
Erlangen, Germany

**March 15th/16th**

Inspection Funding Third Phase of the SFB-TR 87
Bochum, Germany

**16th - 20th April**

2018 Joint ICTP-IAEA School and Workshop on Fundamental Methods for Atomic, Molecular and Materials Properties in Plasma Environments
Trieste, Italy

**23rd - 27th April**

ICMCTF 45 - International Conference on Metallurgical Coatings and Thin Films
San Diego, United States

**20th – 25th May**

9th International Particle Accelerator Conference (IPAC'18)
Vancouver, Canada

**18th – 21st June**

28th Symposium on Plasma Physics and Technology (SPPT)
Prague, Czech Republic

**24th – 28th June**

International Conference on Plasma Science (ICOPS 2018)
Denver, United States

**8th - 11th May**

US Transport Task Force Meeting (US TTF)
San Diego, United States

**2nd - 6th July**

45th European Physical Society Conference on Plasma Physics (EPS)
Prague, Czech Republic

**6th - 11th October**

Plasma School

**11th - 13th October**

Master Class
*Registration deadline June 15th*
Bad Honnef, Germany

## PhD colloquium

# WELTPP

At the end of November, the 20th WELTPP took place in the old convent Rolduc in Kerkrade, the Netherlands. The scientific program was made up of five oral and two poster sessions which covered various topics in the field of low temperature plasma physics with a good balance of theoretical and experimental works. The very interested audience - mostly young researchers - led to a lot of good questions after the talks and fruitful discussions during the poster sessions.

Besides the scientific part, the program was rounded by good food and a guided tour through the old Abbey. For me it was a great pleasure to take part in this workhop and for next year I recommend it for every young researcher in this field.

*Sascha Monje*

# New PIs for the third funding period

In the final funding period of the SFB-TR 87, three new projects will be involved in the existing consortium. Here, we would like to welcome the three new PIs of the projects and briefly present the new project leaders.

**Prof. Sandra Korte-Kerzel** (A7) will become a PI in project A7 *Micromechanical characterisation of the fracture behaviour of nanostructural layers*. She is professor and holds the Chair of Physical Metallurgy and Metal Physics at the RWTH Aachen University since 2013. The department's research focus is the investigation of metallic materials properties and their physical explanation. Project A7 aims at advancing the formulation of a continuous mechanical model for the tailor-made development of (oxi)nitride coatings.

Project B6 *Multi-scale simulation of mass transport through plastics with PECVD coating* is led by **Prof. Thomas Kühne**. The processes and mechanisms of diffusion through PECVD coatings will be investigated in greater depth. Thomas Kühne is professor for Theoretical Interface Chemistry at the Paderborn University since 2014 and the head of the work group Dynamics of Condensed Matter.

**Prof. Matthias Wessling** will become a PI in the project B7 *Molecular transport through plasma-coated polymers - from gas barrier layers to gas separation layers*. In this subproject, the question of whether it is possible to produce polymer layers with custom-made inner porosity and molecular topology by means of plasma processes will be investigated. Since 2010, Prof. Wessling holds the Chair of Chemical Process Engineering (AVT.CVT) at the RWTH Aachen University.


## Impressum

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