## Surface Engineering - Applied Research and Industrial Applications
## Room Sunset - Session G6
## Application-driven Cooperation Between industry and Research Institutions

**Moderators:** Tobias Brögelmann, Surface Engineering Institute - RWTH Aachen University, Joern Kohlscheen, Kennametal GmbH, S.P. Kumar Yalamanchili, Oerlikon Balzers, Oerlikon Surface Solutions AG

1:50pm **G6-2 Performance Evaluation of Precious Metal Coatings in Precision Glass Molding***, **Marcel Friedrichs**, A Saksena, M Hans,* RWTH Aachen University, Germany*; O Dambon,* Fraunhofer Institute for Production Technology IPT, Germany*; J Schneider, F Klocke,* RWTH Aachen University, Germany

Precision Glass Molding (PGM) is a replicative technology for producing complex optical components with high surface quality and form accuracy. The efficiency of PGM process depends primarily on the lifetime of the high-precision molding tools made of cemented tungsten carbide. During each molding cycle, the molding tools have to withstand severe thermo-chemical and thermo-mechanical loads. Using protective coatings, the lifetime of the molding tools can be increased. The most versatile coatings for molding various glass types are based on precious metals due to reduced chemical interaction in contact with heated glass.

In this study, platinum-iridium (Pt-Ir) protective coatings were deposited on cemented tungsten carbide molding tools by physical vapor deposition (PVD) process. The investigated Pt-Ir coatings differed in their chemical composition. Based on predictions of the enthalpy of mixing, additional ternary Pt-Ir-X (X = Cu, Au) coatings were evaluated. To investigate the operational capability of the protective coatings, molding tests were carried out at an in-house built lifetime testing bench and at an industrial glass molding machine. Subsequent analyses of coated specimens were performed by white light interferometry and scanning electron microscopy (SEM). Depending on the chemical composition of the coating, different degradation phenomena as glass adhesion, interdiffusion and coating delamination were observed and discussed.

2:10pm **G6-3 Plasma-dependent Phase Formation of TiAlN Coatings***, **Anders Eriksson**,* Oerlikon Balzers, Oerlikon Surface Solutions AG, Liechtenstein*; M Hans, S Mráz, J Schneider,* RWTH Aachen University, Germany*; M Arndt,* Oerlikon Balzers, Oerlikon Surface Solutions AG, Liechtenstein

The industrial success of TiAlN as wear-resistant and protective coatings is enabled by the well-known favourable age-hardening characteristics. However, the ability to control microstructure, mechanical and thermal properties of the coatings is also essential for application-specific coating design. In this contribution we study the deposition process of coatings deposited from $Al_{67}Ti_{33}$ (at%) targets. By varying the arc source settings, the resulting coating properties have been optimized in industry for different cutting tool applications: either a single phase cubic solid solution or a mixture of cubic and hexagonal phase was obtained. Gaining in-depth understanding of the deposition processes leading to the different phase formation scenarios is a topic in our cooperation for application-inspired fundamental research within an industrial-scale deposition system. For the two arc source settings, we have characterized the plasma composition and ion energies in an Oerlikon Balzers INGENIA P3e™ deposition system by energy-resolved mass spectrometry. The phase formation was observed to depend significantly on the arc source configuration and hence plasma properties. Our findings illustrate that a collaboration between industry and academia enables knowledge-based design of protective coatings for specific applications.

2:30pm **G6-4 Reactive HiPIMS Deposition of Ti-Al-N: How to Adjust the Cubic to Wurtzite Transition***, **Helmut Riedl**, L Zauner, P Ertelthaler,* CDL-AOS at TU Wien, Austria*; T Wojcik,* TU Wien, Institute of Materials Science and Technology, Austria*; H Bolvardi,* Oerlikon Balzers, Oerlikon Surface Solutions AG, Liechtenstein*; S Kolozsvári,* Plansee Composite Materials GmbH, Germany*; P Mayrhofer,* TU Wien, Institute of Materials Science and Technology, Austria

High power impulse magnetron sputtering (HiPIMS) is often seen as one key-technology in the deposition of future hard and multifunctional coating materials. Through the introduction of high amplitude impulses at relatively low duty cycles, the amount of ionized species, either target near gas atoms or sputtered target atoms, can be increased drastically. These highly dense plasmas have various consequences on the film growth and hence coating properties, as well as on the sputter behavior of the target material itself. Applying reactive gas mixtures such as $N_2$/Ar atmospheres, e.g. for the deposition of TiN coatings, lead to further complex effects within the plasmas (self-sputtering, gas recycling, or poisoning). However, several studies clearly highlighted the outstanding coating properties as well as metastable phases accessible, using HiPIMS compared to conventional DC magnetron sputtering, whereas a majority of these investigations concentrate on the plasma physics itself.

Therefore, we focused in this study on the reactive HiPIMS deposition of Ti-Al-N coatings using $Ti_{1-x}Al_x$ compound targets (x = 0.50, 0.60, 0.66, 0.80) in mixed Ar/$N_2$ atmospheres. The influence of the HiPIMS parameters such as frequency, pulse length, and power density, but also of the deposition parameters like partial pressure, deposition temperature, or total pressure was investigated methodically. The so obtained coating structures were analyzed with respect to phase stability, thermomechanical properties, and morphology applying nanoindentation, X-ray diffraction combined with electron imaging techniques (SEM and HR-TEM). In addition, to gain an in-depth understanding of the HiPIMS parameters on the used compound target materials a special in-situ target-temperature measurement system was utilized during all depositions (min. distance to sputtered target surface about 1 mm).

2:50pm **G6-5 AlTiN Coatings deposited by HIPIMS: A Study of Mechanical Properties, Tribological and Wear Performance during Machining of Superduplex Stainless Steel***, J Paiva, **Edinei Locks**, Y Seid Ahmed, P Stolf, J Dosbaeva,* McMaster University, Canada*; C Bork,* IFSul - Federal Institute Sul-rio-grandense, Brazil*; G Fox-Rabinovich, S Veldhuis,* McMaster University, Canada

AlTiN PVD coatings represent a generation of coatings designed to work at high temperature applications. The aluminum in the film converts to aluminum oxide as the coating heats up, resulting in increased oxidation resistance. The use of this coating is related to the cutting tool applications where a lot of heat is generated. In this work, an advanced High Power Impulse Magnetron Sputtering (HIPIMS) technique was utilized to deposit dense AlTiN coatings on cemented carbide cutting inserts. The influence of HIPIMS process deposition was compared with AlTiN PVD Coating deposited by Arc method and evaluated in terms of microstructure, mechanical and tribological properties, by means of SEM /EDS, XRD structural characterization, nanoindentation testing, and Pin-on disc high temperature tribotesting. To relate the coatings properties with the wear performance, cutting tests were performed during turning of superduplex stainless steels at finishing operations. FEM modeling of the turning process was employed to determine the cutting temperatures, cutting forces and stresses at the cutting tool edge. The results obtained demonstrate that the tribological and wear performance of the AlTiN PVD coatings deposited by HIPIMS showed significantly improved wear behavior as compared to arc deposited AlTiN coating. This is because HIPIMS process allows to deposit very dense, defect free coatings, with low residual stresses and excellent surface finish that improves wear performance of the coated tool.

3:10pm **G6-6 FunMat-II – an Industry-Academia Competence Center for Research on Coating Materials for Advanced Applications***, **Lina Rogström**, M Odén, I Abrikosov, G Greczynski, P Eklund, E Björk,* Linköping University, IFM, Sweden

FunMat-II (Functional Nanoscale Materials) is a second-generation competence center in material science, continuing the successful VINN Excellence Center FunMat inaugurated in 2007 (ended 2016). The center starts late 2017 and will continue for five years. FunMat-II is financed by the Swedish Agency for Innovation Systems (VINNOVA), Linköping University and our 12 industry/institute partners.

FunMat-II is focusing its efforts to three application areas for functional surfaces: cutting tools, fuel cells, and batteries. We obtain basic knowledge about materials behavior and the physics and chemistry of the synthesis processes, and design new materials with unique properties. We study all aspects using combinations of theory, modeling, experiments, and field tests. The information obtained is generic and can be applied to a wide range of applications, which makes FunMat-II a true competence center in functional surfaces optimized at the nanoscale.

This presentation gives an overview of the partnership and the way of working within the competence center, including application-inspired fundamental research, industry-oriented PhD education, continuing education, and intellectual property handling. Scientific highlights from recent studies of materials for advanced application are given as examples, including high-temperature contacts [1], *in situ* characterization of hard coatings in turning operations, and experimental and theoretical studies of coatings with improved thermal stability for high-speed cutting [2-4].

[1] H. Fashandi et al., Nat. Mater. 16(8) (2017) 814.

[2] L. Rogström et al., J. Appl. Phys. 118 (2015) 035309.

[3] I. Schramm et al., Acta Mater. 119 (2016) 218

[4] F. Wang et al., Acta Mater. 127 (2017) 124.

3:30pm **G6-7 Oxygen Diffusion Pathways in High Temperature Oxidation Resistant Ti-Al-N/Mo-Si-B Multilayer Coatings**, ***Elias Aschauer,*** CDL-AOS at TU Wien, Austria; *P Felfer,* Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; *M Arndt,* Oerlikon Balzers, Oerlikon Surface Solutions AG, Liechtenstein; *P Polcik,* Plansee Composite Materials GmbH, Germany; *H Riedl,* CDL-AOS at TU Wien, Austria; *P Mayrhofer,* Institute of Materials Science and Technology, TU Wien, Austria

In high temperature oxygen containing atmospheres, the oxidation resistance of a protective coating is mainly based on the ability of the participating metals to form adherent and continuous oxide scales separating the reactants from the oxidizing atmosphere. Corundum type $Al_2O_3$ or $Cr_2O_3$ represents such highly stable oxide structures, whereby the formation of Al-rich scales was crucial in the success story of $Ti_{1-x}Al_xN$. Nevertheless, oxide scales only constitutes semipermeable barriers slowing down scale growth, where the kinetic of the growing scale is determined by the fastest species - e.g. metal or oxygen ion outward and inward diffusion, respectively. With respect to the temperature ($T < 0.6\ T_m$), the dominant transport mechanism in growing scales is along fast-diffusion pathways such as dislocations, voids, or especially column boundaries rather through the bulk crystal lattice. To further enhance the oxidation resistance of e.g. $Ti_{1-x}Al_xN$, a fundamental understanding of the oxidation process and a distinct knowledge on the phase evolution and present diffusion pathways in the atomic scale range is highly desired.

Therefore, we used atom probe tomography (APT) to analyse the diffusion pathways in our high-temperature oxidation resistant Ti-Al-N/Mo-Si-B multilayer coatings. The repeated incorporation of very thin sputtered Mo-Si-B layers ($\lambda \approx 25$ nm) in arc-evaporated Ti-Al-N ($\lambda_l \approx 100$ nm) leads to an interrupted growth of the V-shaped Ti-Al-N columns, and hence to highly distinct areas in 3D chemical mapping. To overcome the difficulty of mass/charge peak overlap during APT investigations, the samples were annealed in $O^{18}$ for 60 min at 900 °C. For optimized volume analysis, three tips parallel to the layered structure, next to the growing scale, were prepared by a standard FIB lift out technique – uniformly distributed from top to bottom in the unaffected coating region. These results were correlated with a detailed analysis on the phase evolution applying nano-beam X-ray diffraction as well as morphology by using high-resolution transmission electron microscopy in the as deposited and thermal treated state.

3:50pm **G6-8 Novel ta-C Coatings with Outstanding Tunable Properties Deposited by Industrially Scaled PLD**, ***Martin Hess,*** Fritz Stepper GmbH & Co. KG, Germany; *S Weißmantel, R Bertram,* Hochschule Mittweida, Germany

ta-C deposited by PVD is successfully introduced for quite some time for wear protection applications of engine components (piston rings, injection parts, etc.). Due to their geometrically relatively simple functional areas, batching as well as a posttreatment of coated surfaces is common compared to more complex shaped parts. Due to its prominent mechanical properties ta-C is actually increasingly introduced to commercial PVD-systems. However, limitations are high intrinsic stresses, roughness and also tribochemistry. As a consequence ta-C is still rarely found on industrial tools for stamping and chip removing processes.

Acting in the spirit of our company founder ("If you want to improve something, you have two options: Optimizing existing procedures or rethinking the whole process") we decided in early 2016 not to add another PVD-system to our equipment park (CARC, PECVD, HIPIMS). We thought rather about a surface enhancement technology which would be dedicated and designed towards our internal requirements to maximize quality of small, one-digit ccm volume, parts in batches of only some 10 to a few 100 pieces per day.

Our primary motivation was that in one of our high performance modular stamping tools up to 5000 moving components are facing stroke rates exceeding 2000 strokes per minute. In this context our boosting ambition is the creation of maintenance free tools up to production lots of 100 million electrical contact parts and more. However even latest PVD-coatings on carbide substrates of highest quality are actually limited to some million strokes before showing critical wear leading to expensive tool downtime. As abrasion was isolated as the dominant life-time limitation our obvious conclusion was to seek for significantly higher abrasion resistance than our latest 35-40 GPa nanolamellar or nanocomposite PVD coatings. At the end ta-C was assessed as the most promising evolution.

Preceding benchmark tests regarding the ta-C coating process options isolated the so far for wear protection applications relatively unknown or rather unusual PLD as a promising process, due to some unique inherent features: smooth surfaces, homogeneous erosion of the target and last but not least: precise control of mechanical coating properties such as Y and H as well as tunable intrinsic stresses by laser energy. As a result smooth and well adherent coatings of up to 6 µm thickness were deposited on steel and carbide substrates. The purpose of the present contribution is to give an introduction to this novel technology and its first successful applications.

4:10pm **G6-9 Application-driven Cooperation Between Industry and Research Institutions: Success Factors, Obstacles and Success Stories**, ***Oliver Lemmer,*** *W Koelker,* CemeCon AG, Germany **INVITED**

Development of new products and new technologies should be triggered by market needs. Depending on the respective subjects and the economic constraints, the market expects those needs to be met either in short term or in mid/long term. Subsequently two major challenges have to be mastered:

1. The different time line expectations have to be addressed by different styles of cooperation and by selectively chosen partners, in order to succeed in creating new products and technologies.

1. The "chicken and egg" problem: new products often need new technologies to produce them.

Recently, two new technologies have gained prominent importance for advanced coatings for demanding applications, e.g. in aerospace industry: HiPIMS technology and CVD diamond technology. In this context, the different roles of partners in R&D-networks will be described, and the different objectives and tasks with respect to the different time horizons will be presented. An outlook will be given on the potential of new products created by the combination of these two high-end technologies.

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