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Protective Ti coatings on BPP for Proton Exchange Water Electrolysis Prepared by HIPIMS Technology

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Proton exchange membrane (PEM) water electrolyzers are one solution for green hydrogen production and currently rely on titanium (Ti) porous transport layers and bipolar plates (BPP) on the anode side to ensure sufficient corrosion resistance and low interfacial contact resistance under highly oxidizing, acidic conditions. However, the use of bulk Ti substantially increases stack and system cost and limits cost effective large-scale deployment. In this work, we investigate Ti-coated stainless steel substrates as a cost-effective alternative to monolithic Ti plates, employing high power impulse magnetron sputtering (HIPIMS) to deposit dense, adherent Ti coatings tailored for PEM electrolyzer operation.

Ti layers are deposited on industrially relevant stainless-steel grades using a HIPIMS process with different peak current and pulse length for high ionization fraction and coating density. The coated substrates are characterized with respect to interfacial contact resistance and corrosion behavior.

The study demonstrates that HIPIMS-deposited Ti coatings can provide a continuous, protective barrier on stainless steel, enabling corrosion resistance and electrical performance suitable for PEM electrolyzer components, while significantly reducing the use of bulk Ti. The combination of low-cost steel substrates with advanced Ti coatings offers a promising pathway to lower material costs and improve the economic viability of PEM water electrolysis without compromising durability or performance.

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Fantastic Coatings and Where to Find Them: A HIPIMS Story

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HIPIMS (High Power Impulse Magnetron Sputtering), and even more especially Reactive HIPIMS (R-HIPIMS), has drawn attention in the thin film community over the last 20 years for its capability to produce high quality, dense, thin films with few defects at an industrial scale. Recent technological progress has even made it possible to finely control ion energy distribution in the discharge, and thus ion bombardment on the growing film. Thanks to HIPIMS, magnetron sputtering moved from an “out of equilibrium process” to a “far away from equilibrium” process, allowing the synthesis of novel, never observed materials.

Our work over the past 10 years showed that it is possible to synthesize thin films of metastable crystalline phases in a stable form. By fine tuning R-HIPIMS parameters, single phased monolayer of both hexagonal (ε, P6/mmm) or cubic (δ, Fm-3m) TaN can be deposited at room temperature on various substrates, without any influence of the substrate on either the phase or its stability. Further work on transition metal nitrides demonstrated that tuning R-HIPIMS parameters can tune functional properties and helps to synthesize never observed metastable phases such as tetragonal VN. Moving to R-HIPIMS in an oxygen reactive atmosphere, we have shown that it is possible to synthesize the stable phase of aluminum oxide, the alpha-alumina at low temperature, namely lower than 400°C. It is far below the usual 1000°C process temperature necessary to obtain α-Al_2O_3 (R-3c)

In parallel, we have conducted simulation studies to explore the growth mechanisms of these thin films with unusual structures. Our molecular dynamics work confirmed that it is possible to simulate the growth of TaN films in either of its crystalline phases obtained via HIPIMS. Structure predictions coupled with DFT calculations further allowed us to confirm the actual phases produced, particularly TaN π(P-62m) and δ phases.

These new materials, beyond the scientific impact of their actual synthesis, open the door to new industrial applications. R-HIPIMS tantalum nitride mono-phased coatings, for instance, demonstrates exceptional properties suitable for use in fuel cell technologies. The combination of advanced synthesis and characterization techniques, along with simulation approaches, underlines the huge potential of R-HIPIMS technique as a versatile tool for materials innovation at the industrial scale.

Our current work now combines material innovation and artificial intelligence approach, to explore the possibilities offered by artificial intelligence methods to assist us in discovering new materials potentially synthesizable by R-HIPIMS. This dual approach aims to accelerate the identification of candidate materials and the R-HIPIMS parameters to reach them, paving the way for further innovation in thin film technologies.

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Combinatorial sampling of CrAlN HIPIMS coatings

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CrAlN is an interesting ternary coating system for wear protection of cutting tools. It closely resembles the well-known TiAlN system but also features some deviating coating properties. In this study, we deposited CrAlN by HIPIMS using nitrogen reactive gas. The flow of nitrogen and Al:Cr elemental ratio was varied. The latter was achieved by using a so-called combinatorial approach with Cr and Al target segments. As experiments were done in an industrial coating unit, we used threefold substrate rotation. Samples of cemented carbide, style CNGA and ISO 10 classification were typically used. Coating thickness was kept around 2 micron which proved to be sufficient for nano-indentation, XRD analysis, and machining tests. It was found that a maximum hardness is obtained for Al:Cr ratios of about 65:35 atomic % reaching plastic hardnesses of close to 35 GPa and modulus values of 450-500 GPa. Interestingly, higher than usual nitrogen gas flow is required. XRD confirmed the presence of cubic CrN phase with grain size (diffraction peaks) decreasing for higher Al contents. Just as with the TiAlN ternary hexagonal AlN is eventually forming which leads to a deterioration of mechanical properties and wear resistance. The effect of coating composition on wear mechanisms in dry and wet turning tests of cast iron work-piece material will be discussed.

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HIPIMS: Advanced Coating Technology from an Industrial Manufacturing Perspective

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High Power Impulse Magnetron Sputtering (HIPIMS) offers new opportunities for sputtered coatings and presents a key technology for future coating solutions. Through continuous technological progress, HIPIMS provides significant potential for improving the performance of established coating systems for tooling, tribological applications and decorative coatings. At the same time, the technology gives access to new markets.

In many industries, the focus is on increasing efficiency and HIPIMS is therefore becoming increasingly important. The technology can be seamlessly integrated into existing production lines and enables the economical production of high-performance coatings such as AlCrN or TiAlXN. In order to meet the requirements of for example R&D institutes, smaller job coaters or regrinders in the tool sector, HIPIMS processes have been successfully transferred to the new entry system Flexicoat 500. This makes the technology accessible to a wider range of users not only in the tool market, but also for tribological and decorative applications.

We present specific coating and application examples that can be adapted to different machine sizes. The adaptation of the process technology, for example through variable operating modes such as bipolar mode, pulse shapes or adjustable pulse lengths, enables performance-oriented increases for demanding machining applications or the precise adjustment of specific coating properties.

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Using W^+ Ion Bombardment To Reduce Energy Consumption During TiAlWN Coating Deposition Under Industrial Conditions

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High mobility of the deposited atoms during growth is necessary to obtain void-free metal-nitride coatings with high hardness. This mobility is usually achieved by high temperature during deposition. However, to reduce energy consumption and to be able to use temperature sensitive substrates, deposition at lower temperature is desired. It was recently found that bombarding the growing film surface with W^+ ions increases adatom mobility, leading to TiAlWN coatings with the same quality as those deposited using the high-temperature (conventional) processing [1-3]. The key parameter that controls film growth under such conditions is the momentum transfer from W^+ ions to film constituents, which depends on the flux of W^+ ions, the W-to-metal ratio and the substrate bias voltage. In [1-3] the W^+ ions are generated by operating a W-target in HIPIMS mode, while the TiAl target was sputtered in DC mode. This study aims to extend the previous work to industrial conditions, which includes considerations of samples with two-fold rotations and of the impact of target wear. Depositions are done using a CemeCon CC800 HIPIMS unit with two TiAl and two W targets in all operated in HIPIMS mode. Synchronized, pulsed substrate bias with values of -60 V, -120 V and -240 V besides floating voltage was used. Substrates were Si wafer and steel pins. Two parallel series of depositions were done: One with relatively new W-targets and one with used W targets. Comparative depositions without W and with the W-target in DC mode are included to investigate the effect of W addition and W^+ ion bombardment. Coating structure is analysed using SEM and XRD, and coating stress and hardness are measured using the Stoney method and by nanoindentation, respectively. Initial investigations showed that using W-target with high wear leads to higher pulse peak currents compared to using a less-worn target, which indicates an expected different degree of ionisation of W. Cross section SEM reveals columnar coatings for all bias voltages, and XRD shows the same phases. At low substrate bias (floating and -60 V) coatings deposited using newer W-targets show more pronounced multilayer structure in both SEM and XRD compared to coatings deposited using worn targets. At high substrate bias (-120 V and -240 V) the coatings are nearly identical. It is also observed that coatings deposited using worn targets are slightly thinner and has lower W-content than the ones deposited using newer targets. Nevertheless, the coating stress and hardness are very similar regardless of target state. The compressive stress increases with bias voltage and the hardness of the coating increases with bias voltage up to 120 V and then remains nearly constant at about 28 GPa. The two reference coatings (no W and W in DC mode) have lower hardness (25 GPa), and the coating deposited using DC mode for the W-target has high compressive stress. The low-temperature TiAlWN coating saves about 40 % energy compared to an industry standard AlTiN coating.

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Time-Dependent Ionisation Region Modelling of Ti/Ar HIPIMS and e-HIPIMS Discharges

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In this work, a time-dependent ionisation region model (IRM) is used to study how the applied voltage waveform affects Ti/Ar HIPIMS and enhanced-HIPIMS (e-HIPIMS) discharges. In e-HIPIMS, a multilevel power supply makes it possible to superimpose additional short pulses on the main discharge [1,2], providing additional control over the temporal evolution of the plasma and, consequently, the conditions of Ti thin-film growth. The model is based on the balance equations for neutral and charged species in the ionisation region, coupled with the electron power balance. It predicts the time evolution of the electron temperature and electron density, together with the densities of the main neutral and ionic species involved in the discharge.

The model is then used to examine the influence of operating parameters such as pressure, gas flow rate and duty cycle, with particular attention to the effect of the additional short pulses used in e-HIPIMS. The calculations show that these pulses alter the temporal evolution of the plasma composition, especially the balance between argon and titanium species. This behaviour is consistent with time-resolved studies showing a transition from an early gas-dominated stage to a later metal-dominated stage in HIPIMS discharges [3].

Overall, these results highlight the interest of IRM modelling for comparing HIPIMS and e-HIPIMS operation and for analysing how pulse design influences metal ionisation and the conditions of Ti sputtering.

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Time Resolved Optical Emission Spectroscopy of e-HIPIMS Discharges

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Unlike standard HIPIMS, enhanced-HIPIMS enables dynamic modification of pulse voltage waveforms by superimposing additional voltage pulses [1,2]. Our prototype system uses five series-connected generators (each: 300 V max, 1 µs resolution) to create complex waveforms. For example, as shown in Figure 1, a - 400 V HIPIMS pulse is applied using two generators, each set to a voltage of - 200 V for 31 µs (P0 profile). An additional voltage of - 200 V can be added at any time during the discharge, offering precise temporal control over discharge chemistry and plasma dynamics. All pulse configurations investigated are shown in Figure 1.

Current-voltage measurements show a clear increase in the discharge current when the additional pulse is applied, indicating a strong modification of the discharge dynamics regarding a conventional HIPIMS regime. To examine the corresponding plasma response, time-resolved optical emission spectroscopy (OES) was carried out for several pulse configurations.

The optical measurements show that the timing of the additional pulse strongly affects the relative evolution of Ar, Ti and Ti^{+} emissions throughout the discharge (Fig.2). These measurements show that the additional pulse changes the transition from an early gas phase only to a later metal-enriched phase. The decrease in Ar emission is consistent with changing excitation conditions as Ti sputtering develops, which seems to induce by lowering electron temperature and density. In addition, the Ti^{+}/Ti emission ratio strongly depends on the timing of the additional pulse, with the highest values obtained for the P2 and P5 configurations. These results show that pulse shaping in e-HIPIMS is an effective way to adjust the plasma species and, consequently, to influence metal ionisation in HIPIMS plasmas. This could provide more flexibility in adjusting the electrical and mechanical properties of the Ti deposited film according to the specifications.

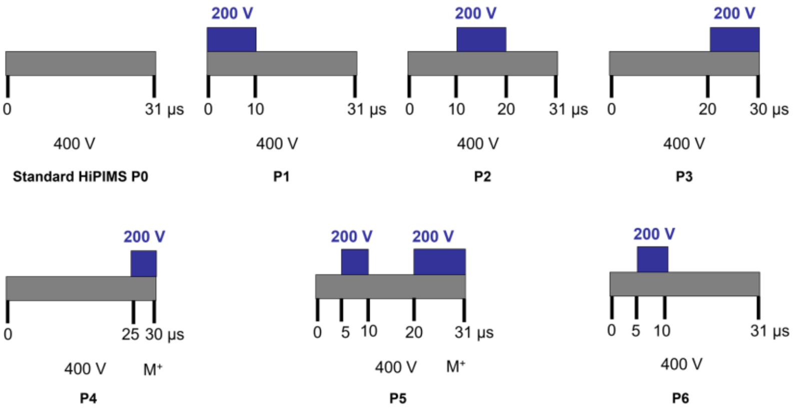

Figure 1: Pulse configurations used in the e-HIPIMS experiments.

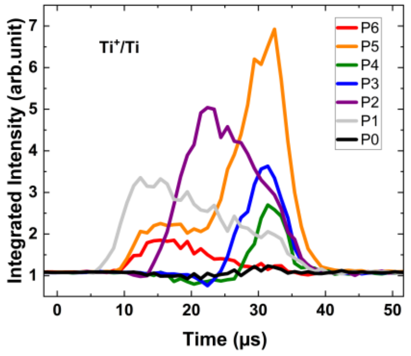

Figure 2: Ti^{+}/Ti ratio for each e-HIPIMS pulse configuration.

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Time Resolved Investigations on Ion Fraction, Ionization Degree, and Plasma Composition within a HIPIMS Pulse

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High Power Impulse Magnetron Sputtering (HIPIMS) has established itself as a state-of-the-art technique for thin film deposition. Optical emission spectroscopy (OES) is a powerful, non-invasive diagnostic tool for characterizing HIPIMS processes, particularly when applied in a time-resolved manner. Such investigations provide detailed insight into transient plasma dynamics, which can be exploited to deliberately tailor advanced coating processes. In addition, progress in simulation and modeling approaches significantly accelerates both process development and physical understanding.

In this work, a combined experimental and numerical approach is presented, employing time-resolved OES together with particle-in-cell Monte Carlo (PIC-MC) simulations to study single-pulse HIPIMS discharges of titanium. Initial results reveal the temporal evolution of ion generation, including neutral titanium atoms as well as singly and doubly charged titanium ions, as measured by time-resolved OES. The corresponding PIC-MC simulation results show good agreement with the experimental observations, thereby supporting the underlying physical interpretation. Finally, the influence of the applied charging voltage on ion generation and on the resulting ion-to-neutral ratio is examined, offering guidance for the targeted optimization of HIPIMS process conditions for coating applications.

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Hybrid Cleaning of Components Prior to High-Tech Coating

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It is well known that high-tech coating processes require significantly higher component cleanliness compared to conventional coating methods. A wide variety of, sometimes unknown, contaminants must be reliably and reproducibly removed. The search for an optimal cleaning process, especially regarding the increasingly important cost-benefit ratio (unit costs), presents a major challenge.

In this context, it is interesting to consider the still underrepresented use of modern organic solvents in combination with aqueous cleaning media.

Here, the important principle of cleaning technology, "like dissolves like" [1], must be taken into account. This principle means that hydrophilic contaminants should preferably be removed with aqueous media, and lipophilic contaminants with organic solvents such as modified alcohols or isoparaffins.

Often, there are very diverse contaminants from both groups, and additionally, of course, non-soluble contaminants such as metallic or mineral particles. In this case, hybrid cleaning processes, such as the Hybrid or Beyond process [2] from HEMO, become interesting and advantageous.

In the Hybrid process, organic solvents such as isoparaffins (hydrocarbons with chain lengths C9 to C14) or modified alcohols are first used in the same working chamber to remove lipophilic contaminants, followed by aqueous media with detergents to remove hydrophilic contaminants. After the aqueous stage, a final solvent stage is performed before the final drying.

It is important to recognize the enormous advantages of the overall process, which takes place in one working chamber or cleaning system in sequence, compared to carrying out the treatment steps in several separate cleaning systems. This relates, for example, to issues such as the prevention of corrosion or the perfection of part drying.

HEMO already offers the market many proven processes.

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HIPIMS Coatings for Micro Tools

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It's a clear trend: cutting tools are becoming smaller and more precise. It started with watchmaking and today's drivers for this development are medical and dental as well as the 3C industry. AI technology makes PCB tools for drilling computer boards a high-volume application for extremely small tools. The explosion of computing power turned simple two-sided computer boards into highly sophisticated stacks of 10 or more layers which must be precisely interconnected. The super dense packaging in electronics makes a drill of Ø0,25 mm the new standard and requires board materials with ceramic fillers or glass interlayers.

HIPIMS is the best suited coating technology for micro tools since it gives smooth coatings without any droplets, a dense and fine-grained morphology of the film together with low intrinsic stresses.

More knobs to turn – HIPIMS gives effective control over the plasma. The multiple settings of HIPIMS allow the energy pulses to be tailoring for micro tools. This avoids antenna effects and defects because of over-etching the fine geometry. Precision machining with micro tools requires super sharp cutting edges. The unique HIPIMS feature of synchronizing the pulses at the cathodes with the HIPIMS Bias supply is the key to actively managing the intrinsic stresses in the film.

While PCB drilling is about repeatability and keeping the cost per piece as low as possible, the medical industry demands the uttermost precision for micro machining of implants. Typical materials such as titanium with its low heat conductivity and sintered CoCr which is very abrasive, demand coatings with high hardness, oxidation resistance, and premium adhesion. HIPIMS elevates Si-doped coatings – a chemical composition which is well tested in the medical industry – to the next level. The fine-grained structure of the film and the tunable intrinsic stresses allows for higher Si content and thereby higher hardness in mass production machining. HIPIMS metal ions follow the field lines and arrive perpendicular to the surface of the substrate for a homogeneous 3D coverage of the cutting tool. Controlling the HIPIMS pulse parameters effectively avoids excessive coating at the cutting edge or the tool tip – a typical issue for other PVD methods – for tighter tolerances in coating production.

HIPIMS, with its unique combination of favorable properties, opens new business opportunities in the growing market of precision and micro-machining.

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High-Power Pulsed Bipolar Dual-Magnetron Sputtering Technology Using Cylindrical Cathodes for Deposition of Advanced Coatings in Industrial Applications

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The machining industry faces increasing demands for higher productivity through shorter coating cycles and higher cutting speeds, particularly for difficult-to-machine ferrous and non-ferrous alloys. Meeting these requirements calls for advanced coating technologies that combine high deposition rates with superior film quality.

Cathodic Arc Evaporation (CAE) is widely used in the tooling industry, as it produces coatings with high density, hardness, and deposition rate. However, it inherently generates macroparticles that increase surface roughness. High-Power Impulse Magnetron Sputtering (HIPIMS) can achieve comparable coating properties with significantly lower roughness, albeit at a reduced deposition rate. Surface quality may further deteriorate due to micro-arcing and discharge instabilities when less conductive nitride compounds form on the target. To mitigate micro-arcing, reversed-pulse HIPIMS introduces a positive voltage pulse immediately after the main negative pulse to discharge the target surface and accelerate positive ions toward the substrate, thereby enhancing coating density and hardness. However, anode disappearance—caused by the progressive coating of chamber surfaces with non-conductive material—remains unsolved in single-magnetron configurations.

This contribution presents PLATIT’s recently developed TRM® (Twin Rotating Magnetron) technology, installed in the Pi111 coater. The TRM® consists of dual rotating cylindrical magnetrons with a Closed Unbalanced Magnetic Field (CUMF), powered by a single Bi-Pulse HIPIMS supply operated in asymmetric mode. In this configuration, one magnetron operates at high power (up to 13 kW) while the other serves as a low-power (0.5 kW) self-cleaning anode. Each magnetron alternates its polarity during consecutive half-cycles of the pulse period, sequentially acting as a cathode and as a positively biased anode. Because the anode is not grounded but actively biased, it is continuously cleaned by ion bombardment, effectively eliminating the anode disappearance problem.

The combined effect of high average target power density, the CUMF geometry, and the dense Me^+ plasma generated during short HIPIMS pulses enables a high Ion Current Density to the Substrate (ICDS). The high ICDS, together with excellent process stability, allows fast deposition of high-performance coatings without requiring high substrate bias. Coating growth is further controlled through synchronized pulsed substrate biasing, selectively utilizing the metal-ion-rich portion of the sputtered flux.

AlTiN, AlCrN, and TiSiN coatings were deposited from alloy cylindrical targets in an $Ar+N_2$ atmosphere. Coating performance was evaluated by adhesion testing, structural and microstructural analysis (TEM), nanoindentation, and cutting tests including side milling and micro milling. Results demonstrate that TRM® coatings achieve comparable or superior hardness and adhesion relative to CAE-deposited coatings, with significantly improved surface finish, as validated by cutting performance in industrial machining conditions.

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Effect of carbon content on the structural, mechanical and corrosion properties of TiC films deposited using a HIPIMS discharge

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TiCx thin films have been deposited on steel substrates using High Power Impulse Magnetron Sputtering (HIPIMS) under Ar-C2H2 atmosphere. The effect of varying the acetylene content on the deposition process, and on the structural, mechanical and corrosion resistance properties was investigated by X-ray diffraction (XRD), scanning electron microscopy (SEM), nanoindentation, scratch testing, potentiodynamic polarization, electrochemical impedance measurements (EIS), and salt spray. This study showed that an increase of the carbon ratio affected the deposited Ti–C coatings morphology and mechanical properties, with hardness values reaching up to 25 GPa. The near-stoichiometric coating exhibited the highest hardness while maintaining improved toughness, resistance to plastic deformation and resistance against crack propagation thanks to their nanocomposite structure. In contrast, corrosion tests showed that the understoichiometric coatings exhibited the best corrosion resistance in a 3.5 % wt NaCl medium. The drop of the corrosion performances of TiCx coatings deposited at higher acetylene flow rate was linked to a growth-related defect extending throughout the coating thickness, formed due to micro-droplet ejection from the target as evidenced by SEM analysis.

Keywords: HIPIMS, Titanium carbide, Nanocomposite, Corrosion

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HIPIMS Growth of Ordered Magnetic Alloys: Opportunities and Challenges

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Conventional magnetron sputtering is an essential thin-film deposition technique underpinning modern information technologies, including hard disk drives and emerging spintronic devices. In this context, precise tuning of film density, crystallographic ordering, grain structure, and interfacial quality are achieved by sensitive control of deposition parameters and in-situ process monitoring. However, optimal structural and magnetic properties often require high growth or post-deposition annealing temperatures. For example, heat-assisted magnetic recording (HAMR) relies on materials with strong perpendicular magnetic anisotropy (PMA) and small grain sizes, such as $L1_0$-ordered granular FePt and MnAl in the τ-phase, which typically require fabrication temperatures of ~600–700 °C [1, 2] and ~500 °C [3], respectively. The formation of $L1_0$-FePt as a function of post-deposition annealing temperature is exemplified in Fig. 1, which shows X-ray diffraction (XRD) data from a 20 nm thick FePt film fabricated via DC magnetron sputtering [4].

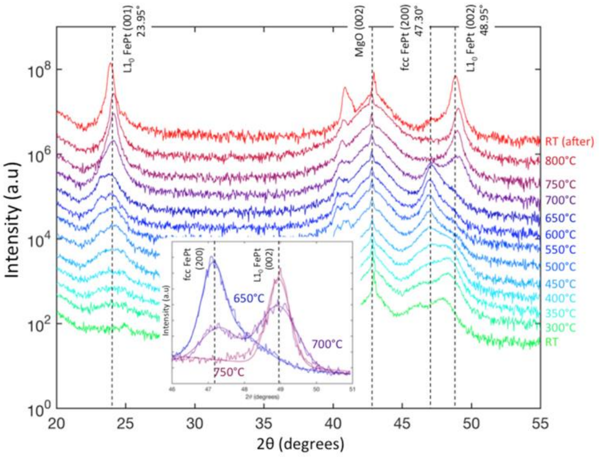

Fig. 1: XRD data from an FePt film deposited via DC magnetron sputtering. The L10 phase begins to emerge at 650 ˚C.

High-power impulse magnetron sputtering (HIPIMS) may offer a promising pathway towards reducing these high temperature requirements, and thus improving compatibility with back-end-of-line (BEOL) processing and heterogeneous device integration. The high ionisation fraction and energetic ion flux characteristic of HIPIMS plasmas may enhance adatom mobility and facilitate short-range chemical ordering at reduced substrate temperatures. Such effects raise the possibility of achieving highly ordered magnetic alloys (including $L1_0$ and Heusler systems) without the extreme annealing conditions traditionally required. Here, we assess the opportunities and challenges of HIPIMS as a route to low-temperature fabrication of high-anisotropy magnetic thin films for data storage and spintronic applications.

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Copper Plasma Characteristics and Power-Supply Parameter Effects in HIPIMS for Through-Glass Via Metallization

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Copper plasma generated in High Power Impulse Magnetron Sputtering (HIPIMS) discharges produces a high fraction of ionised sputtered species, enabling the deposition of dense and conformal thin films. In semiconductor manufacturing, these plasma characteristics are particularly relevant for metallisation of Through-Glass Vias (TGV), where the formation of conformal seed and barrier layers in high-aspect-ratio structures remains a significant process challenge. This work investigates how HIPIMS copper plasma characteristics and power-supply parameters influence film formation in glass vias with aspect ratios of approximately 10:1–20:1.

The study examines how electrical excitation conditions influence copper plasma emission signatures and the resulting film properties. Plasma behaviour was monitored using optical emission spectroscopy under systematically varied ignition voltages (800–2000 V), discharge current densities (0.25–1.25 A/cm²), and pulse durations ranging from 5 to 200 µs. Complementary thin-film characterisation on glass substrates included four-point probe measurements of sheet resistance, deposition rate analysis, and adhesion testing.

Systematic variations in optical emission intensity indicate increased copper plasma emission intensity with increasing discharge current, ignition voltage, and pulse duration. These trends suggest that copper ionisation dynamics play a key role in the formation of conductive and continuous metallisation layers within glass vias.

The influence of ion acceleration through synchronised substrate biasing is discussed qualitatively, together with alternative ion-energy transfer mechanisms that may occur during reverse discharge intervals when external biasing is not applied. By combining plasma diagnostics with thin-film characterisation, the study identifies HIPIMS operating regimes that provide insight into the relationship between copper plasma ionisation and conformal metallisation in high-aspect-ratio glass vias.

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Growth-Controlled Photochromism in Yttrium Oxyhydride Thin Films Deposited by HIPIMS and Pulsed-DC Magnetron Sputtering

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The present study investigates photochromic oxygen-containing yttrium hydride (YHO) thin films deposited by reactive high power impulse magnetron sputtering (HIPIMS) and compares their photochromic, optical, and structural properties with those of films synthesized by reactive pulsed direct current magnetron sputtering (pulsed-DCMS). Optical emission spectroscopy reveals that, unlike pulsed-DCMS where Ar+ ions dominate, HIPIMS discharges are characterized by strong Y+ emission, evidencing high yttrium ionization and substantial self-sputter recycling. The working pressure is systematically varied for both deposition techniques to assess its influence on film properties. The critical working pressure (Pc) required to obtain transparent and photochromic films is higher for HIPIMS (Pc ≈ 1.0 Pa) than for pulsed-DCMS (Pc ≈ 0.5 Pa). Although films deposited near Pc exhibit similar solar transmittance (~72 %) and lattice parameters (5.38–5.39 Å), the pulsed-DCMS film shows a substantially higher relative photochromic contrast (34 %) and a lower optical band gap (2.70eV) compared with the HIPIMS film (9 % contrast and 2.94 eV). This difference is partly attributed to a lower oxygen-to-hydrogen atomic ratio in the pulsed-DCMS film. Structurally, HIPIMS films are largely polycrystalline with random out-of-plane crystallographic orientation, whereas pulsed-DCMS films exhibit a pronounced <100> out-of-plane preferred orientation. These results demonstrate that, beyond composition, thin-film growth conditions and microstructure play a crucial role in governing the photochromic performance of YHO.

Keywords: photochromism, oxygen-containing yttrium hydride, YHO, HIPIMS

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Superposition of HIPIMS with RF on a Single Magnetron: Generation of High Ion Energies

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High power impulse magnetron sputtering (HIPIMS) has shown significant potential for thin film deposition by providing high ionized flux fractions [1] and ion energies [2]. To optimize the deposition process, HIPIMS can be operated in superposition with an additional discharge on the same magnetron, such as DC [3] or MF (mid-frequency pulses) [4]. This superposition method increases the deposition rate and enables low-pressure operation by using pre-ionization from the continuous discharge during the off-time between pulses.

In this study, a novel combination of HIPIMS and RF (radio-frequency, 13.56 MHz) is investigated in continuous superposition on the same magnetron, using a planar copper target in argon atmosphere [5]. The discharge is characterized at varied power ratios of HIPIMS and RF with plasma diagnostics employed to analyze the system. This includes measuring the combined HIPIMS/RF voltage signal and conducting optical emission spectroscopy (OES) to gain insights into the plasma composition. Two key factors influencing the microstructure of deposited films are the kinetic energy of particles bombarding the growing film and the substrate temperature [6]. Substrate heating from the plasma is evaluated using a passive thermal probe (PTP) [7], a “non-conventional” calorimetric diagnostic that measures the total energy flux to the substrate surface. The kinetic energy is assessed through energy-selective mass spectrometry, including time-resolved operation. The results regarding the plasma parameters are compared with the morphology of the deposited copper films, analyzed using scanning electron microscopy (SEM).

Addition of an RF plasma provides pre-ionization for the HIPIMS pulses, which allows to reduce the process pressure. Time-resolved OES reveals the transition from the copper-dominated emission during the HIPIMS pulse to an argon plasma in in the HIPIMS off-time. The RF plasma exhibits a pronounced influence on the ion energy distribution, increasing the ion energy by more than 50 eV depending on the applied RF power. This effect is attributed to an increased plasma potential caused by the RF sheath, which accelerates ions in the sheath region toward the substrate, resulting in elevated ion energies. The potential of this method is demonstrated by the deposition of copper thin films, showing significant influence of the deposition mode for their properties [5].

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RF-Assisted HIPIMS Operation on a Single Target: Discharge Stabilization and Ionization Behavior in Arcing-Prone Processes

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High Power Impulse Magnetron Sputtering (HIPIMS) is widely recognized for its ability to generate highly ionized plasmas, enabling dense and well-adherent thin films. However, certain target materials and reactive processes remain challenging for HIPIMS operation due to discharge instability and a high probability of arc events. This work investigates the use of RF assistance on a single target as a method to improve discharge stability while maintaining the high ionization characteristics typical for HIPIMS plasmas.

Hybrid HIPIMS+RF operation was studied using time-resolved and full-spectrum optical emission spectroscopy together with electrical diagnostics of the discharge. Several synchronization strategies between the RF excitation and HIPIMS pulses were evaluated, including continuous RF operation, RF applied only during HIPIMS pulses, and RF applied during the HIPIMS off-time. The influence of RF power fraction on plasma behavior was investigated while maintaining constant total power, allowing direct comparison of ionization characteristics and discharge stability across different operating regimes.

The measurements indicate that RF assistance during HIPIMS operation can significantly reduce the occurrence of arc events on silicon targets and stabilize the discharge behavior, while the introduction of HIPIMS pulses into an RF discharge enhances the contribution of ionized sputter species. Systematic variations in target current–voltage characteristics and peak current behavior were observed under hybrid excitation, providing insight into how combined RF and HIPIMS power delivery influences plasma dynamics.

The results demonstrate that RF-assisted HIPIMS operation offers a viable strategy for extending HIPIMS processing to materials and conditions that are prone to arcing under conventional HIPIMS operation. The study highlights the importance of power-delivery timing and synchronization for controlling discharge stability and plasma ionization behavior in hybrid RF-HIPIMS systems.

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Antimicrobial Activity of Superhard Nanostructured and Plasmonically Active TiN-Based Coatings

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In the face of the antimicrobial resistance crisis – the rapid increase in the prevalence of disease-causing microorganisms that are resistant to antimicrobial drugs – there is an urgent need for antimicrobial strategies that are independent of antibiotics and similar drugs. Such strategies would be effective against resistant pathogens. Also, since the spread of antimicrobial resistance is driven largely by the use of antimicrobial drugs, being able to use less of them would slow the worsening of the crisis.

Surfaces of solid materials are substantial vectors for transmission of infections in the indoor built environment, particularly in healthcare settings. They are also highly significant in difficult-to-treat infections of indwelling medical devices such as replacement hips and knees, where biofilms of microorganisms on the surface of the material can cause infections that can currently only be treated by further surgery to replace the infected device. Key target microorganisms are the Gram-positive *Staphylococcus* bacteria, including MRSA, Gram-negative bacteria such as *Escherichia coli* (*E. coli*) and *Pseudomonas*, and pathogenic yeasts such as *Candida*.

The interdisciplinary ROMANS project (RObust Manufacturable ANtimicrobial Surfaces) has combined HIPIMS coating technology with colloidal lithography to produce novel metamaterials with superhard plasmonically active nanostructured surfaces. These materials are designed to have a dual mode of antimicrobial action: (1) physical penetration of the microorganisms by sub-micron scale pillars or spikes on the surface; (2) chemical killing of the microorganisms by reactive oxygen species produced photocatalytically under illumination with electromagnetic radiation. The resulting nanostructured TiN surfaces show significant UV-induced killing of the Gram-positive pathogen *Staphylococcus aureus* (1-1.5 log, ≈90-97 % kill) and much greater killing of the Gram-negative pathogen *Pseudomonas aeruginosa* (4 log, ≈99.99 % kill). These results compare very favourably with other antimicrobial materials that operate via nanostructures or photocatalysis, which typically achieve 1-2 log kill (90-99 % kill) from materials that are generally less physically robust than the metamaterials we have prepared.

The presentation will conclude with a discussion of the remaining challenges that must be met to translate these results into valuable new medical devices and other products to combat the antimicrobial resistance crisis.

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Room-Temperature Fabrication of TiN Plasmonic Nanoarrays on Flexible Substrates via HIPIMS

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Constant improvement of ceramic coatings for cutting tools aiming at best wear resista Transition metal nitrides (TMNs) have recently attracted significant attention as viable alternatives to conventional noble metals for plasmonic and optoelectronic applications operating in the visible and near-infrared (NIR) spectral regions. A major limitation, however, is that achieving optical properties suitable for plasmonics typically requires high deposition temperatures (>800 °C), restricting compatibility with temperature-sensitive substrates.

In this work, we demonstrate the deposition of plasmonic titanium nitride (TiN) thin films at room temperature using high-power impulse magnetron sputtering (HIPIMS), without intentional substrate heating. The HIPIMS process enhances the energy of both metal ions and dissociated nitrogen species (N^+), enabling the formation of high-quality TiN films at low temperatures. This approach allows direct deposition on a wide range of technologically relevant substrates, including flexible polymer platforms.

Building on this capability, we fabricate TiN plasmonic nanoarrays via colloidal lithography, achieving tunable nanostructures with feature sizes in the 100–500 nm range. The resulting arrays exhibit controllable geometries and dimensions, enabling precise tailoring of plasmonic properties. Optical characterisation reveals tunable resonances across the visible and NIR spectral regions, in strong agreement with numerical simulations presented here.

These results establish a scalable pathway for integrating plasmonic TMN materials into flexible and temperature-sensitive devices, opening new opportunities for applications in flexible photonics, sensing, and optoelectronics.

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HIPIMS-Deposited Nanoscale Multilayer Coatings to Enable Plasmonic Photocatalysis for Antimicrobial Surfaces

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The evolution of pathogens to resist antibiotics is a persistent threat facing our society due to the accelerating incidence of untreatable infections and difficulties in developing new highly efficient drugs. Plasmonically-enabled photocatalytic surfaces are a promising weapon of attacking the question as they are readily activated by light activation and produce reactive oxygen species which are both biocompatible and detrimental to microorganisms. Plasmonic photocatalysts rely on efficient conversion of incident photonic energy by plasmons in the material and confinement of the plasmons within a nanoscopic resonator. For practical use, the former needs to have high absorption and low losses while the latter requires mechanical robustness.

Nanoscale multilayer thin films of TiN and NbN deposited by HIPIMS were patterned using inductively coupled plasma etching into nanoscopic pillar arrays to create a series of surface plasmon resonators. Colloidal masks were used to produce a nanopillar pitch of 400 nm. Plasma diagnostics revealed the presence of highly ionised nitrogen with evidence of metastable states which could be responsible for high current densities in the discharge causing the cathode voltage to drop despite poisoning the target surface. Significant photoluminescence was observed at 600 nm with excitation of 532 nm. The constant-current nature of the discharge allowed for fast ignition and the simultaneous production of gas and metal ions. Compared to TiN coatings deposited in the same system configuration, the crystallographic texture of TiN/NbN coatings switched to (200) on account of a large ion momentum brought by Nb^{1+} ion bombardment. The texture tailoring resulted in increased grain size, densification of the grain boundaries and reduced plasmon scattering. Pump-probe laser measurements indicated a factor 2 longer lifetime of highly energetic electrons within the materials as a result of grain boundary densification. Ellipsometry measurements of the dielectric permittivity indicated a metallic optical behaviour (highly negative real component), and high absorption. Losses (ratio of real and imaginary components) were reduced for denser grain boundary films. The nanoscopic pattern arrays exhibited an optical absorption peak at 800 nm indicating a clear surface plasmon resonance. When activated by ultraviolet light, the surfaces achieved a very significant kill rate of *Pseudomonas Aeruginosa* of log 4 compared to inert substrates including stainless steel and glass. Mechanical testing using pin-on-disk systems revealed considerable resistance to wear against a 6 mm alumina ball counterpart under a load of 1 N with nanopillar structures visible after several hundred laps and stable friction coefficient.

Overall, the results clearly show that HIPIMS-deposited nanoscale multilayer coatings with a surface nanopattern are highly robust and plasmonically active, and represent a potent antimicrobial class of materials.

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Tribological Performance of Nano-Patterned Nanoscale Multilayer TiN/NbN Coatings Prepared by HIPIMS

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Nanopillars of transition metal nitrides (TMNs), such as TiN and NbN, show strong potential for photocatalytic, plasmonic, and antimicrobial applications; however, their mechanical robustness remains largely unexplored. Understanding their wear mechanisms is therefore critical for practical deployment.

In this work, superhard TiN/NbN multilayer coatings (thickness 2.2 ± 0.1 µm, hardness 29 ± 1 GPa, adhesion LC_2 = 80 N) were deposited on Ti substrates using High Power Impulse Magnetron Sputtering (HIPIMS). TiN/NbN nanopillar arrays with a pitch of 400 nm and a diameter of 330 nm were subsequently carved via colloidal lithography followed by reactive ion etching. The mechanical resilience of this nanopillar array was evaluated in ambient conditions using a pin-on-disk apparatus using a 6 mm Al_2O_3 ball sliding at 0.1 m s^{-1} under 1 N load.

Interrupted wear tests combined with FIB cross-sectioning and Raman spectroscopy were used to analyse wear mechanisms, friction evolution, and debris/tribolayer composition. Results revealed that the friction coefficient (µ) increased progressively with sliding distance, reaching ~1 after 1500 laps (~150 m), followed by a quasi-steady state around 1.2 up to 2500 laps (~188 m). Wear proceeded via gradual nanopillar attrition and tribolayer formation, which partially protected the surface. The tribofilms consisted primarily of Ti and Nb oxides and was periodically removed by roll formation, re-exposing the nanopillars. FIB analysis showed no fracture or plastic deformation; instead, wear occurred through layer-by-layer removal of TiN and NbN nanolayers driven by tribo-oxidation. These results demonstrate that the nanopillars retain structural integrity under sliding, combining high hardness with notable toughness.

Key words: Sliding-wear, HIPIMS, TiN/NbN, Nanopillar-arrays, colloidal lithography

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Titanium Nitride Deposition by Constant-Current Regulated HIPIMS for Plasmonic Applications: Influence of the Discharge Composition and Pressure

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A series of current-regulated HIPIMS discharges of Titanium Nitride were investigated with varying levels of nitrogen gas flows. The discharges were investigated using a Plasma Sampling Mass Spectrometer fixed at the substrate position allowing for the analysis of ion flux incident at the substrate surface. TiN thin films were also deposited for each of the investigated conditions, with 100 nm and 1 µm thicknesses. The created films were analysed using X-ray Diffraction (XRD), Atomic Force Microscopy (AFM), Ellipsometry and Nanohardness Indentation. Analysis of the discharge voltage and deposition rate revealed a rapid shift towards a poisoned regime when nitrogen flow was increased. Mass spectroscopy showed the evolution of the different ionic species within the discharge, with the presence of Ar and Ti doubly charge ions being present within all the investigated conditions, the average temperature of ions was also extracted from the measured Ion Energy Distribution Functions (IEDFs). XRD analysis revealed a texture shift that became more dominated by (111) planes as the nitrogen flow was increased. Ellipsometry revealed that all the created films exhibited optically metallic behaviour, where nitrogen flow can be used to tune the crossover wavelength of the film.

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The Role of Cleaning Prior to High-Performance Coating: Choosing the Right Cleaning Chemistry

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Many coating defects originate not from the coating process itself, but from insufficient or inappropriate pre-cleaning steps. For advanced coating technologies such as HIPIMS, the cleanliness and surface preparation of components are directly tied to coating adhesion, microstructure, and long-term functional performance.

This presentation explores the critical influence of component cleaning on coating quality and provides a practical framework for selecting the most effective cleaning process based on contamination type, substrate material, and end-use performance requirements.

We will compare solvent-based cleaning, aqueous multi-stage systems, and integrated hybrid approaches – highlighting where each excels and where limitations must be addressed.

Attendees will gain actionable guidance for evaluating their current cleaning practices, making informed technology choices, and establishing robust surface-preparation workflows that directly improve coating reliability and manufacturing efficiency.

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Poster 1

Single Photon Emitter Based on Nano-Structured Silicon Nitride Thin Film

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In this work, a possible single photon emitter was fabricated by using nitrogen-rich silicon nitride nano discs. The deposition process of the nitrogen-rich silicon nitride thin film was conducted and optimized by magnetron reactive sputtering. The nano disc structure was realized using sparse colloidal lithography, electron beam lithography and a newly-developed method called dipping colloidal lithography with ion milling. Photoluminescence spectra was conducted to characterise the spectrum of the photon emitter based on the silicon nitride nano disc using 532 nm excitation laser. The lifetime of the photon emitter was also measured and the value is around 0.3 ns.

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Poster 2

Investigating Langmuir-Blodgett Deposition Parameters on the Surface Coverage of Polystyrene-Coated Glass for Use as Substrates for TiN Deposition via HIPIMS

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Colloidal lithography is one of the most highly versatile nanofabrication methods, able to create ordered molecular monolayers with nanometre precision at low cost. Promising applications of colloidal masking include the deposition of antimicrobial thin films, which are nanostructured surfaces designed to kill bacteria or prevent biofilm formation, and polymer masks for transition metal nitrides, which have applications in plasmonics and optoelectronics. A widely established colloidal lithography method is the Langmuir Blodgett (LB) technique, able to deposit close-packed, uniform configurations of colloidal polystyrene (PS) nanospheres onto photocatalytic titanium nitride (TiN) substrates. Conversely, recent research has shown that the PVD technique HIPIMS can successfully deposit TiN onto PS-coated substrates at room temperature, without the requirement for high temperatures. Despite the technique's ever-increasing use, it is unclear how the Langmuir-Blodgett deposition conditions which affect the uniformity and surface coverage of the deposited thin film are influenced by each other.

The goal of this research is to investigate the potential links between LB trough parameters and area coverage of polystyrene-coated substrates such that substrates can be coated reliably for TiN deposition by design, rather than through empirical trial-and-error. The work presented in this poster shows preliminary results obtained from coating 5x8 cm^2 glass substrates with PS spheres of equal diameter (400 nm) but under different deposition conditions. Depositions performed at higher surface pressures and optimal subphase pH give rise to higher coverage areas. Optical microscope images show that the surface area is generally well-covered within the range of compression speeds used, with a minimum surface coverage of approximately 74.3% at a compression speed of 10 cm^2/min and a maximum coverage of about 96.2% at a compression speed of 20 cm^2/min, providing useful insights for LB experimental situations.

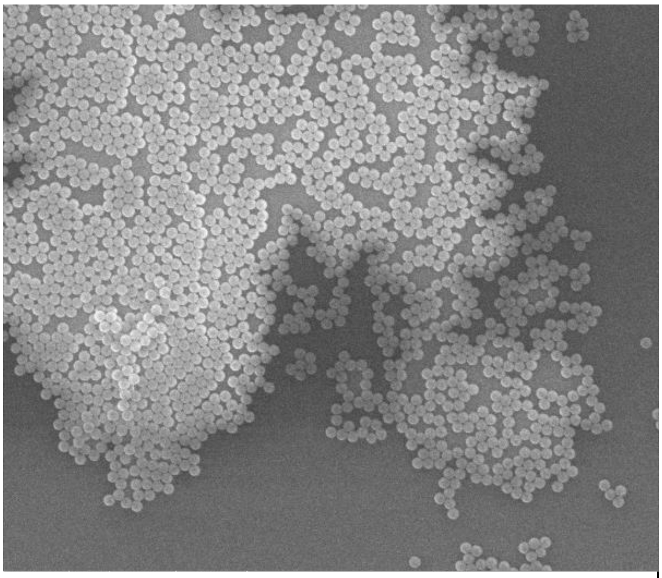

Fig. 1: *SEM image of PS-coated substrate*

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Poster 3

Additive Manufacturing of Thermally Conductive AlN Ceramic Components for Industrial Application

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Thermal management is a crucial factor affecting the performance and lifetime in several applications, such as electronics, generators, and heat exchangers. As devices become increasingly miniaturized and integrated, their thermal power consumption rises, making effective heat dissipation a critical challenge. This study explored the use of Aluminium Nitride (AIN), which offer exceptional thermal conductivity, wear and corrosion resistance, electrical insulation and a coefficient of thermal expansion, making them an ideal candidate for advanced heat dissipation solutions. Vat photopolymerization (VPP) 3D printing technique was employed for the fabrication of AlN components due to its capabilities to produce high-precision, complex geometries with excellent surface quality. This research investigated the formulation of a AlN ceramic suspension, optimising the type and ratio of photosensitive resin, and sintering additives to enhance rheological properties, printability, and final component properties such as density, thermal conductivity, mechanical strength and thermal stability. The feasibility of this approach to generate complex-shaped parts was successfully shown by fabrication of crack-free demonstrator parts, highlighting prospective novel use cases in advanced heat management applications.

Key words: Additive Manufacturing, Vat photopolymerization (VPP), Aluminium Nitride (AlN), Thermal Conductivity

NOTES

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