

Functional Ceramic Coatings

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1. Introduction

Modern materials engineering, just like other areas of today's science and technology, requires a comprehensive and balanced approach that takes into account all factors that affect not only the design and functional properties of materials, but also their economic profitability and rational management of the available resources. A reflection of this trend is the continuous improvement of the performance, functionality and versatility of engineering designs, which entails the need for new and/or precisely tailored materials.

In many cases, the surface properties of materials or devices are crucial for their application and operation. Therefore, it is advisable to apply the methods of surface engineering, leading to modifications in the structure and properties of the surface layers of materials, or deposition of coatings on their surface.

The advantage of the latter solution is, above all, the possibility of wider use of advanced materials with unique functional properties, which, for various reasons, cannot or should not be used as the bulk. Particularly interesting in this case is the group of ceramic materials, which in form of the coatings can significantly improve the functionality and applications of classic engineering materials, such as metals (and their alloys) or polymers. Ceramics is an important group of coating materials because of its wide range of controllable features, such as mechanical strength and hardness, corrosion resistance, electrical conductivity, surface properties (surface energy, catalytic behavior, biocompatibility), optical properties, etc. Using these features, it is possible to create tailored substrate-coating systems. From this point of view, it is crucial to understand the relationships between the structures, morphology and the properties of ceramics in the form of coatings.

2. Functional Ceramic Coatings

The aim of the "Functional Ceramic Coatings" Special Issue was to present the progress in the development of ceramic coatings for various purposes, with an emphasis on the influence of their internal structure and morphology on functional properties and potential applications. The Special Issue consisted of fourteen fully refereed scientific publications, the topics of which included:

- Bioactive/biomedical applications [1–4]
- Barrier and protective properties [5–7]
- Mechanical and anti-wear properties [8–10]
- Optical and photocatalytic properties [11,12]
- Deposition and adhesion mechanisms [13,14]

In the first topic, there were four publications related to the biomedical applications of ceramic coatings. Kyzioł et al. [1] presented their work on the deposition of various multi-layer coatings based on diamond-like carbon structures deposited on low-density polyethylene (LDPE). The tailored plasma pre-treatment and deposition of thin DLC-like coatings resulted in an improvement of the mechanical properties (higher hardness with favourable gradient) and wettability of the LDPE surface (as an important property in osseointegration processes), while maintaining good biocompatibility of the surface without



Citation: Pietrzyk, B.; Miszczak, S. Functional Ceramic Coatings. *Coatings* **2021**, *11*, 130. <https://doi.org/10.3390/coatings11020130>

Received: 20 January 2021

Accepted: 22 January 2021

Published: 26 January 2021

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significant changes in cell viability in vitro. Jonauske et al. [2] presented the results of their research on the manufacturing of thin calcium hydroxyapatite ($\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$; CHA) films on stainless steel using the sol-gel method. Using this method, the authors produced good-quality hydrophobic CHA coatings, which induced the formation of amorphous calcium phosphate (ACP) in the environment of simulated body fluid (SBF). This could improve osseointegration and promote bone cell proliferation for a better bone-implant connection and biocompatibility. In the next article, Burnat et al. [3] developed Ca and Ag ions doped TiO_2 coatings, deposited by sol-gel dip-coating method on M30NW biomedical steel. Comprehensive characterization of the obtained coatings showed an anatase-based structure and anticorrosive, hydrophilic, and bioactive properties. The results of the biological evaluation indicated that independently of the Ca and Ag ions molar ratio, the obtained coatings are biocompatible and do not reduce the proliferation ability of the osteoblasts cells. The last work on the biomedical/bioactive topic was an article by Pietrzyk et al. [4] describing SiO_2 coatings modified with hydrophobizers and zinc compounds. The coatings, produced by the sol-gel method, were characterized in terms of their morphology, chemical structure, and antibacterial properties. It was found that zinc compounds, unlike hydrophobizers, had a crucial impact on the antibacterial properties of the coatings, preventing formation of *Escherichia coli* biofilm.

The second leading topic of the Special Issue was the barrier and protective properties of ceramic coatings. Very interesting research results were presented by Yu et al. [5], who proposed an innovative method of producing a protective coating based on Al_2O_3 - SiO_2 compound. The Al powders were successfully encapsulated by SiO_2 and the SiO_2 @Al slurry was used to coat the surface of carbon J55 steel. As a result, a new type of Al_2O_3 - SiO_2 ceramic coating (ASMA) was formed that exhibited excellent high temperature protective properties against oxidation. In the next article by Banaszek and Klimek [6], Ti(C,N) coatings with various chemical composition were deposited by magnetron sputtering method on Ni-Cr Heraenium NA alloy as a barrier coatings. In-depth studies of the release of Ni and Cr ions into aqueous solutions have shown very good barrier properties of these coatings, therefore they can significantly contribute to reducing potential cytotoxicity and improving the biocompatibility of prosthetic alloys. The last work on the barrier ceramic coatings was that of Liu et al. [7], about the microstructure and mechanical properties of 8% yttria-stabilized zirconia (8YSZ) thermal barrier coatings deposited on Ni-based superalloy (GH3128) by plasma spraying. The authors analyzed the effect of the parameter-dependent plasma spraying deposition process on the microstructure of the coatings and their micromechanical properties. Then the trans-scale mechanics theory was adopted to characterize the nanoindentation size effect for the micron-/nano-grain microstructure of the coatings. Highly convergent simulation and experimental results showed much better micromechanical properties of the nano-grain YSZ coatings.

The mechanical and anti-wear properties of ceramic coatings was the third topic of the Special Issue. This topic was taken up by Grimm et al. [8], who investigated the structure, phase composition, and mechanical properties (including wear) of the Al_2O_3 - Cr_2O_3 - TiO_2 coatings. The authors showed that even in multi-component blends of oxides the dominant single oxide has a significant influence on the coating properties. The use of powder blends deposited by atmospheric plasma spraying (APS) presents a promising approach to adapt or extend the property profile of plain oxide coatings. The next two papers were focused on the friction and wear properties of the coatings. In their work, Kula et al. [9] described the new concept of low frictional hybrid MoS_2 / WS_2 /FineLPN composite coatings on nodular cast iron. Researchers used a hybrid coating method combining MoS_2 + WS_2 slurry deposition with two types of thermo-chemical treatment: FineLPN low pressure nitriding, and sulphur nitriding. This unconventional approach resulted in coatings with a layered microstructure, very low dry friction coefficient (0.13) and low linear wear. Interesting results were also obtained by Pietrzyk et al. [10], who used the sol-gel method to produce Al_2O_3 + graphene composite coatings on stainless steel substrates. The authors analyzed the influence of two types of graphene nanoplatelets (GNPs) and the parameters of coatings

deposition on their microstructures and basic tribological properties, obtaining in some variants the dry friction coefficient of 0.11.

The fourth topic covers the optical and photocatalytic properties of the ceramic coatings. The article by Wen et al. [11] presents the properties of photocatalytic TiO₂ coatings deposited with modified atmospheric plasma spraying (APS) method. Water injection into the plasma jet allowed the modification of the solidification of the molten TiO₂ particles and induced nucleation of the desired anatase phase. As a result, TiO₂ coatings with 5-times higher anatase content and better photocatalytic activity were produced. In the second article, Szymanowski et al. [12] presented a novel method for deposition SiNC/SiOC optical coatings with a gradient of refractive index. The deposition was performed using radio frequency plasma-enhanced chemical vapor deposition (RF PECVD) technology from organosilicon compounds with a variable composition of N₂/O₂ gas mixture, resulting in a single-layer optical coating with the gradient of refractive index. The method developed was used to manufacture a high quality “cold mirror” type of interference filter.

The last Special Issue topic was related to deposition and adhesion mechanisms of ceramic coatings. Deposition mechanisms and thickness control were the main topics of the work of Wang et al. [13] on the SiC coatings on NextelTM440 fibers. The authors synthesized carbon-rich SiC coatings on Nextel fibers using the CVD method, proposed an empirical formula to calculate the coating thickness, and presented a detailed mechanism of the reactions taking place during the deposition of the coating on the surface of the fibers. The topic of coating-to-substrate adhesion was explored by Omar et al. [14] in their work on the deposition of TiO₂ coating on stainless steel substrate by the cold-spray process. The obtained results proved the important role of annealing of austenitic 304 steel on the bonding of sprayed TiO₂ particles to its surface. Adhesion between the brittle TiO₂ particles and the stainless steel surface was attributed to a high-velocity collision that caused limited amorphization and mixing of atoms in the interface zone.

As the editors, we encourage readers to read this Special Issue. We hope that this reading will show the possibilities and variety of applications of ceramic coatings and will inspire readers to deepen their interest in this topic. Finally, we would like to express our appreciation to all the authors for their contribution to the development of research in the field of ceramic functional coatings.

Funding: This research received no external funding.

Acknowledgments: As guest editors, we would like to thank Bunny Zou, Section Managing Editor, for her support. We also wish to thank all the contributing authors and reviewers for their excellent work.

Conflicts of Interest: The authors declare no conflict of interest.

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