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Review of PVD-Derived Nanolayers on the Surface Properties and Biocompatibility of Polymers

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Abstract: *Physical vapor deposition has emerged as an effective surface-engineering technique for modifying polymeric biomaterials without substantially changing their bulk properties. PVD-derived nanolayers, particularly those produced by magnetron sputtering, high-power impulse magnetron sputtering and related physical deposition processes, can introduce controlled changes in surface chemistry, roughness, wettability, adhesion, mechanical durability and biological response. This is particularly important for polymers used in biomedical applications because many polymers possess desirable bulk characteristics such as flexibility, low density, processability and biodegradability but may exhibit inadequate surface properties for direct contact with biological tissues. Research published during 2010–2020 demonstrates that nanometer-scale Ti, TiO_2, titanium–nitrogen, calcium-phosphate and related coatings can improve the interaction between polymer surfaces and biological environments.*

Keywords: Physical vapor deposition, PVD, nanolayers, polymeric biomaterials, magnetron sputtering, surface modification, biocompatibility.

I. INTRODUCTION

Polymeric materials have become increasingly important in biomedical engineering because of their versatility, relatively low density, flexibility and ability to be fabricated into complex structures. Materials such as polyetheretherketone (PEEK), poly-L-lactic acid (PLLA), polycaprolactone (PCL), polyhydroxyalkanoates and polyurethane have been investigated for applications including tissue-engineering scaffolds, vascular devices, drug-delivery systems and implantable components. However, the biological performance of a polymer is not determined solely by its bulk properties. Surface characteristics such as wettability, surface energy, chemical composition, nanoscale roughness and functional-group availability strongly influence protein adsorption, cell adhesion, proliferation and differentiation. Consequently, surface modification has become an important strategy for improving polymer–tissue interactions while retaining the advantageous bulk properties of the polymer.

PVD is particularly attractive because it permits the deposition of very thin functional layers onto a substrate. In biomedical applications, magnetron sputtering is one of the important PVD approaches because it can deposit metallic, oxide and ceramic materials under relatively controlled conditions. The deposited layer can modify the outermost surface without requiring modification of the entire polymer matrix. A 2020 review of PVD coatings for medical devices emphasized that PVD can modify surface properties while preserving the underlying mechanical or biomechanical characteristics of the substrate.

II. PVD-DERIVED NANOLAYERS ON POLYMERIC SUBSTRATES

PVD encompasses several physical processes in which material is vaporized from a solid source and subsequently deposited as a thin film on a substrate. Magnetron sputtering is especially relevant for polymers because it enables deposition of materials such as titanium, titanium oxide and calcium phosphate at comparatively low substrate temperatures. This is important because many biomedical polymers have limited thermal stability. During magnetron sputtering, energetic ions bombard the target, ejecting atoms that travel toward the substrate and form a nanoscale coating.

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Process variables such as discharge power, deposition time, gas composition, substrate bias and target material determine the resulting film thickness, composition, morphology and adhesion.

A major advantage of PVD is that the surface and bulk properties can be separated. Instead of changing the complete polymer composition, only the outer surface is engineered. This approach can be particularly beneficial for biodegradable polymers, where changes to the bulk polymer could alter degradation rate or mechanical properties. Research on PCL electrospun scaffolds showed that sputter deposition of titanium increased titanium and oxygen content at the surface and increased hydrophilicity while also affecting pore characteristics. Similarly, titanium coatings deposited on PCL/PHBV electrospun scaffolds were found to improve cellular adhesion and demonstrate proangiogenic potential.

III. MODIFICATION OF SURFACE WETTABILITY

Surface wettability is one of the most important characteristics affected by PVD-derived nanolayers. Polymer surfaces can be relatively hydrophobic, which may limit favorable interactions with aqueous biological environments. Deposition of inorganic nanolayers can alter surface energy and contact angle, thereby changing the adsorption of proteins and subsequent cellular responses. In biomedical applications, controlled hydrophilicity is frequently associated with improved interaction between the material and physiological fluids.

Reactive magnetron sputtering of titanium onto electrospun PLLA scaffolds was reported to increase the hydrophilicity of the polymer surface without significantly changing its physicomechanical properties. Similar changes in hydrophilicity have been reported for PCL scaffolds subjected to titanium sputter deposition. These findings indicate that PVD nanolayers can be used to tune the interface between polymeric materials and biological fluids. However, an excessively hydrophilic or chemically active surface is not automatically superior; the final biological response depends on the combined effects of chemistry, roughness, protein adsorption and coating stability.

IV. INFLUENCE ON SURFACE ROUGHNESS AND MORPHOLOGY

Surface topography at the nano- and microscale plays an important role in biological interactions. PVD deposition can produce changes in grain structure, surface roughness and nanoscale morphology depending on deposition parameters. These characteristics can influence protein adsorption and cell attachment. Research on biomaterial surfaces has emphasized that physicochemical characteristics such as roughness, surface chemistry and wettability collectively regulate cellular behavior. Rahmati et al. (2020) highlighted the importance of biomaterial surface physicochemical properties in controlling biological responses.

For polymeric scaffolds, this effect is particularly important because electrospun materials already contain a complex fibrous structure. PVD treatment must therefore be sufficiently controlled to coat the fibers without blocking pores or destroying the scaffold architecture. Studies involving PCL/PHBV scaffolds showed that deposition parameters influenced the surface relief and amount of deposited titanium, demonstrating the close relationship between PVD conditions and scaffold morphology.

V. IMPROVEMENT IN CELL ADHESION AND PROLIFERATION

One of the primary objectives of PVD surface modification is to improve cellular interaction. Cell adhesion represents an early stage in the biological response to an implanted material and is influenced by surface chemistry, roughness, wettability and protein adsorption. PVD-derived Ti-based nanolayers can provide surfaces that are more favorable for cell attachment than untreated hydrophobic polymers.

A particularly relevant study investigated titanium coatings deposited by magnetron sputtering on bioresorbable PCL/PHBV electrospun scaffolds. The researchers evaluated cell adhesion, viability and secretion of biological factors and reported enhanced cell adhesion following titanium deposition. The modified scaffolds also demonstrated proangiogenic activity, suggesting that PVD treatment can potentially improve the biological functionality of polymeric vascular-tissue-engineering materials.

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Similarly, titanium-containing nanolayers prepared on PLLA scaffolds improved hydrophilicity and were associated with improved biocompatibility in an animal model. Importantly, the study reported no adverse tissue reaction up to three months after subcutaneous implantation of the modified scaffolds. These findings indicate that PVD modification can affect both initial cell–surface interactions and subsequent tissue responses.

VI. PVD MODIFICATION OF PEEK

PEEK is an important high-performance polymer used in biomedical applications because of its mechanical properties, chemical stability and relatively favorable biological characteristics. However, its relatively inert surface can limit direct biological integration. Consequently, PVD has been investigated as a method of adding bioactive or osteoconductive layers to PEEK.

High-power impulse magnetron sputtering was used to deposit crystalline TiO_2 films onto PEEK substrates at low temperature. The study demonstrated that appropriate control of the oxygen-to-argon ratio enabled formation of anatase and rutile TiO_2 coatings, and the coatings exhibited in-vitro biocompatibility. This is important because low-temperature processing is desirable for polymer substrates that could be damaged by conventional high-temperature coating processes. The results support the possibility of converting an otherwise relatively bioinert polymer surface into a more biologically interactive interface through a thin PVD-derived oxide layer.

VII. PVD MODIFICATION OF PLLA AND PCL

Biodegradable polymers such as PLLA and PCL are extensively investigated for tissue engineering because their degradation can be matched to tissue regeneration. However, their surface properties may not always be optimal for cellular attachment. PVD provides a means of modifying these properties without completely changing the polymer's degradation behavior.

In PLLA scaffolds, reactive magnetron sputtering using a titanium target produced a surface coating that increased hydrophilicity while maintaining the principal physic mechanical properties of the scaffold. In-vivo observations also indicated favorable tissue interaction. In PCL scaffolds, sputter deposition of titanium altered surface composition, pore characteristics and hydrophilicity, while cell adhesion and viability were also investigated.

These results suggest that PVD is especially valuable for biodegradable polymer scaffolds because it provides a relatively thin modification layer rather than a thick secondary material that could interfere with degradation or scaffold architecture.

VIII. CRITICAL ANALYSIS OF THE LITERATURE

The literature from 2010–2020 indicates that PVD-derived nanolayers can significantly improve the surface functionality of polymeric biomaterials. One of the most consistent observations is that PVD treatment can increase surface hydrophilicity and improve cellular interaction. Titanium and titanium-based layers are particularly attractive because titanium is widely associated with favorable biological responses and can be deposited in very thin layers. TiO_2 is also useful because its chemical stability and biological compatibility make it suitable for biomedical surface engineering. The successful deposition of TiO_2 on PEEK using HIPIMS demonstrates that even relatively inert high-performance polymers can be modified using low-temperature PVD techniques.

A second important finding is that the biological response is strongly influenced by nanoscale surface morphology. A coating that is chemically biocompatible may not necessarily produce optimal cell adhesion if its roughness, crystallinity or wettability is inappropriate. The literature on calcium-phosphate coatings particularly emphasizes the importance of thickness, morphology and crystal structure in determining cell behavior. Therefore, future optimization should focus on controlling multiple surface parameters simultaneously rather than considering chemical composition alone.

A third issue is the possibility of damaging the polymer during PVD processing. Polymers are more sensitive to energetic particle bombardment and elevated temperature than metallic substrates. The processing conditions must therefore balance adequate coating adhesion with preservation of polymer morphology and mechanical properties. The studies on

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electrospun PLLA and PCL/PHBV demonstrate that appropriate control of deposition conditions can produce useful surface modification while preserving the essential scaffold architecture.

IX. CONCLUSION

The literature published between 2010 and 2020 demonstrates that PVD-derived nanolayers represent an effective strategy for improving the surface properties and biocompatibility of polymeric biomaterials. PVD techniques, particularly magnetron sputtering and HIPIMS, can deposit nanoscale titanium, titanium oxide, titanium-based compounds and calcium-phosphate layers onto polymers while retaining many of the beneficial bulk characteristics of the substrate. Studies involving PEEK, PLLA, PCL and PCL/PHBV have demonstrated improvements in surface hydrophilicity, cellular adhesion and biological compatibility following carefully controlled PVD treatment.

Overall, the evidence suggests that the performance of PVD-modified polymers depends on the interaction between coating chemistry, thickness, surface morphology, crystallinity, wettability and coating–substrate adhesion. Calcium-phosphate research further demonstrates that nanoscale structural characteristics can directly influence cell responses. Thus, PVD should not simply be considered a coating technique but rather a surface-engineering approach capable of independently tailoring the biological interface of polymeric biomaterials. Continued development of low-temperature, highly controlled and multifunctional PVD processes may contribute significantly to the design of safer and more effective polymer-based biomedical devices.

REFERENCES

1. Direct metallization of PMMA with aluminum films using HIPIMS. (2016). Surface and Coatings Technology, 290, 77–81.
2. Enhancement of bioactivity on medical polymer surface using high power impulse magnetron sputtered titanium dioxide film. (2015).
3. Geyao, L., Yang, D., Wanglin, C., & Chengyong, W. (2020). Development and application of physical vapor deposited coatings for medical devices: A review. Procedia CIRP, 89, 250–262.
4. Qadir, M., Li, Y., & Wen, C. (2019). Ion-substituted calcium phosphate coatings by physical vapor deposition magnetron sputtering for biomedical applications: A review. Acta Biomaterialia, 89, 14–32.
5. Rahmati, M., Silva, E. A., Reseland, J. E., Heyward, C. A., & Haugen, H. J. (2020). Biological responses to physicochemical properties of biomaterial surfaces. Chemical Society Reviews, 49, 5178–5224.
6. Surface modification of electrospun poly-(L-lactic) acid scaffolds by reactive magnetron sputtering. (2018). Colloids and Surfaces B: Biointerfaces.
7. Surface modification of poly-ε-caprolactone electrospun fibrous scaffolds using plasma discharge with sputter deposition of a titanium target. (2016). Materials Letters, 171, 87–90.
8. The use of magnetron sputtering for the deposition of thin titanium coatings on the surface of bioresorbable electrospun fibrous scaffolds for vascular tissue engineering: A pilot study. (2017). Applied Surface Science, 398, 63–72.