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REVIEW

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Electrochemical Behavior of Dental Alloys after Surface Modification by Sputtering Coating Technique

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Abstract

For metallic materials, the corrosion behavior is the most important property to be considered due to the biocompatibility and cytotoxicity of the products of the corrosion process in vivo. Numerous coating processes have been developed to improve corrosion resistance, enhance the metal's surface qualities, and increase its service life. The purpose of this review was to gather data on the corrosion of alloys in dentistry and plasma sputtering coating techniques to improve the surface characteristics of substrates. Several databases, including google scholar, pubmed, science direct, and web of science were searched electronically, and a manual search of the scientific literature was also carried out. Both searches were undertaken concerning this subject. This research provides a summary of the findings from seventy-seven studies that were conducted between the period from 2015 to 2025.We utilized the following keywords: "dental alloy, corrosion resistance, surface modification, sputtering coating technique". According to the reviewed articles, Sputtering is an approach that is mostly utilized for the purpose of depositing various coatings in order to enhance the surface qualities of substrates. These properties include appearance, resistance to corrosion, resistance to wear, resistance to scratching, and biological compatibility.

Keywords: Dental alloy, Corrosion resistance, Surface modification, Sputtering coating technique

1. Introduction

For many years, metals and their alloys, as a crucial category of biomaterials, have been extensively utilized in various biomedical applications, including dentistry [1]. Metals, in addition to the other three materials (ceramics, polymers, and composites), are mainly used in dentistry to restore damaged, decayed, or missing teeth [2]. Due to their exceptional mechanical and biological properties, metallic alloys have been utilized in dentistry for hundreds of years [3]. They are extensively utilized in crown prosthesis, orthodontic devices, dental implants, and plates and screws for tissue regeneration and jaw defect restoration [4]. In biomedical applications, metals particularly titanium and cobalt-chromium alloys are recommended, primarily due to their mechanical qualities, electrical and thermal conductivity, biocompatibility, and resistance to high temperatures in general [5]. Nickel-chromium (Ni-Cr) alloy and cobalt-chromium (Co-Cr) alloy demonstrate inadequate protection against corrosion in the oral cavity environment. However, they are frequently employed in prosthodontics as a cost-effective substitute for the costly precious metals due to financial concerns [6].

Xing et al. [7] tested the surface characteristics and corrosion resistance of Co-Cr alloys fabricated via computer numerical control machining (CNC), selective laser melt processing (SLM), and lost-wax casting. This in vitro investigation indicates that SLM printing and CNC machining offer a more

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homogeneous microstructure and enhanced corrosion resistance compared to the casting group. The corrosive behavior of six Ni-Cr and two Co-Cr alloys was evaluated and compared in Ringer's solution by Garcia-Falcon et al. [8]**.** Utilizing electrochemical impedance spectroscopy (EIS), microstructural analysis, and potentiostatic polarization curves. The oral cavity is highly conducive to electrochemical behavior. It experiences significant temperature and pH variations and is warm and humid. To regulate electrochemical effects and, as a result, minimize corrosion and corrosion-induced difficulties in dentistry, it is vital to have a solid grasp of corrosion and the electrochemical properties that lie behind it [9].

Corrosion is a natural process that causes the degradation and deterioration of materials, particularly metals. It is the result of electrochemical or chemical reactions between a substance and its environment [10,11]. One of the most important considerations in the picking of metals and alloys for use in-body applications is potential corrosion. During corrosion processes, irritating, toxic/cytotoxic, or carcinogenic species (for example, nickel, cobalt, chromium, vanadium, and aluminum) may be emitted into the human body [12]. Corrosion invariably results from tarnish, defined as "a surface discoloration on a metal or a slight loss of the surface finish or gloss as a result of thin film formation, such as surface oxides, sulfides or chlorides." It is frequently an initial indication of corrosion [13]. Increased porosity, lost marginal accuracy, strength loss, and the dissolution of metallic substances into the oral environment are all consequences of severe corrosion [14].

A surface modification attempts to enhance the surface characteristics of metallic materials. Applying these dental alloy modifications in conjunction with surface layering materials may effectively reduce corrosion-related complications [15]. Coating with various layers, including oxides, carbides, or metal nitrides, is the conventional approach [6]. Various coatings are employed to enhance surface properties, including adherence, wettability, resistance to corrosion, abrasion, and scratching, and biological responses, depending on the coating's properties. Any coating's main goal is to alter the original substrate's surface characteristics [16]. These Coatings can be composed of different kinds of materials, including polymers, ceramics, and metal alloys [17].

The process whereby various materials are sputtered or evaporated is known as physical vapor deposition (PVD). This technique facilitates the formation of ions, molecules, or atoms, which are subsequently transported to the substrate surface, as a consequence of which a thin coating is produced on the substrate [18].

The purpose of this review was to gather data on the corrosion of alloys in dentistry and plasma sputtering coating techniques to improve the surface characteristics of substrates.

2. Materials and methods

2.1. Study methodology

Digital investigation in Google Scholar, ScienceDirect, PubMed, and Web of Science to find the related articles published between 2015 and 2025 through the keywords: dental alloy, corrosion resistance, surface modification, Sputtering coating technique and their synonyms. The references to the resulting articles also lead to another one.

2.2. Inclusion criteria

Studies published between 2015 and 2025 in English were included if they investigated the corrosion actions of metallic alloys used in dental applications for implants or restorations. Only studies that employed sputtering techniques for coating such as RF or DC magnetron sputtering, were considered.

2.3. Exclusion criteria

Studies were excluded if they employed coating methods other than sputtering techniques, such as sol-gel, electroplating, dip coating, or chemical vapor deposition. Additionally, articles were not considered if the primary purpose of the coating was unrelated to corrosion resistance for instance, coatings aimed solely at improving biological properties without evaluating corrosion behavior. In addition, studies written in languages other than English.

3. Corrosion behavior

Corrosion is an electrochemical reaction that depends on the ability to carry electrical current, either through free electrons in metallic substances or by ions in solution [9]. Metal corrosion is always a reaction of oxidation and reduction. The electrons are released, resulting in the oxidation of the liberated ion, and the electrons (which cannot remain alone) are picked up by certain molecules in the solution (which are therefore reduced) [14].

Dental alloys corrosion in the mouth causes not only the impairment of restorative treatments but also the discharge of ions that are associated with their biological compatibility [19].

The metallic structures within the oral cavity are prone to corrosion due to exposure to a range of

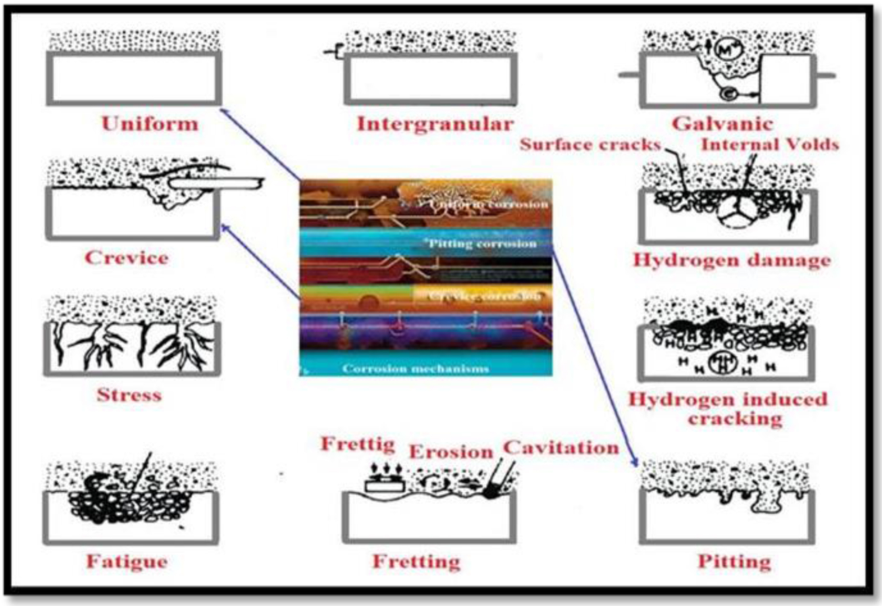

Fig. 1. illustrates the different corrosion mechanisms [10].

intra-oral (such as oral biofilm and saliva) and extra-oral (including food, beverages, and oral hygiene practices) factors [20].

The reduction in pH levels in saliva is a critical factor that exacerbates galvanic and chemical corrosion [21], as noted in individuals with periodontal diseases [22] and those with multiple tooth decay [23]. Systemic diseases can also change saliva's pH levels [24].

Corrosive chemicals, including chloride, floride, and hydrogen ions, are present in saliva, oral biofilms, preventive commercial items (such as whitening toothpaste, mouthwashes, fluoride-based preventive gels), as well as in various foods. There is a correlation between the presence of chloride and the corrosion of metallic implants and restorations. As a result of their high diffusivity, chloride ions are able to efficiently flow through the passive film. It accumulates at the metal/film contact. At the metal/film contact, chlorine ions may react with the metal substrate to generate metal chloride. The surface film experiences rupture as a result of volumetric expansion, attributed to metal chloride's larger molar volume than metal oxide in the surface film. Consequently, pit nucleation takes place [25].

Additionally, metallic appliances are susceptible to mechanical-chemical corrosion as a result of chewing load and dental care products. Tribocorrosion is the term used to describe the friction and attrition that occur between two metallic components in a corrosive medium. In individuals with allergies, metal ions may trigger kind four hypersensitivity reactions, primarily affecting the dermis and oral tissues, leading to sensations of burning in the oral cavity. Additionally, metal hypersensitivity has the potential to cause autoimmune disorders affecting joints, skin, and salivary glands. Additionally, metal ions enter the body through swallowing saliva and may accumulate in different organs and tissues. Dental alloy side effects are typically linked to allergic responses, which can manifest clinically as skin irritation, rashes, Quincke's swelling, and Eczema [26].

3.1. Types of corrosion mechanisms

Some examples of these types of corrosion are stress cracking, corrosion fatigue, fretting, intergranular, galvanic, and localized (pitting and crevice). The synergistic electrochemical and mechanical factors result in stress cracking corrosion, fatigue corrosion, and fretting corrosion [27] as shown in (Fig. 1).

3.1.1. Galvanic corrosion

Galvanic corrosion occurs in dental applications due to galvanic coupling when dissimilar alloys make contact with oral tissues [13, 28]. The establishment of a galvanic cell leads to metal dissolution, producing currents when saliva infiltrates prosthetic parts in contact with dental implants. Currents are generated as a result of the induced potential difference that occurs during the disintegration of metal, as illustrated in (Fig. 2). Galvanic corrosion in dental implants is associated with complex electrochemical processes

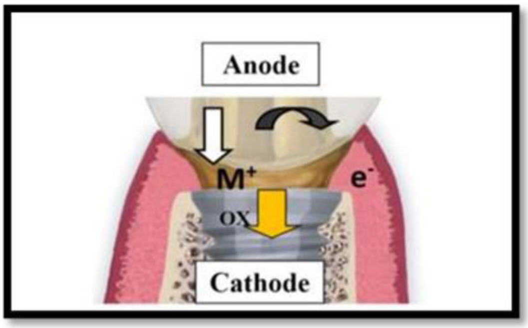

Fig. 2. In implants, a galvanic couple is established where the more active metal (less noble) functions as the anode, releasing metal ions into the medium, while the less active metal (more noble) serves as the cathode [21].

of the implant and suprastructure, which creates a scenario that is significant to treat for two reasons: initially, the biological impacts that may occur from the dissolving of alloy constituents, as well as the bone degeneration induced by the electric current stemming from the galvanic coupling. The metal that corrodes within the couple is the less noble or more active alloy (anode). Therefore, it is necessary to prevent these galvanic couplings [21].

3.1.2. Crevice corrosion

Another kind of corrosion happens when there are fluctuations in the electrolyte composition of the system. Crevice corrosion occurs at the interproximal areas due to food debris and bacteria that alter the electrolyte composition, making it different from normal saliva [9]. The restriction of oxygen transport into the fissure creates a differential aeration cell between the exterior surface (bulk environment) and the crevice (microenvironment). Fissures, joints, and the areas beneath corrosion deposits, regardless of whether they are metallic or non-metallic, are all places where oxygen is rapidly depleted. There will be localized corrosion that is localized in the area that has a low concentration of oxygen, which acts as an anode [29].

3.1.3. Pitting corrosion

The outcome of the presence of corrosion-related substances, the surface pits caused by this type of corrosion are more difficult to spot than those caused by other types of corrosion. Small, extremely corrosive pits that continue to expand downwards and perforate the framework of metal are characteristics of these pits. Pitting is related to many problems, one of which is the localized increase in stress caused by the pit. This stress has the potential to cause cracks to occur [30].

3.1.4. Intergranular corrosion

Metals and alloys have a microstructure that is composed of grains that are separated from one another by grain boundaries along which, or even close to, a localized attack of intergranular corrosion can be identified, while there is no effect recorded for the bulk of the grains [31].

3.1.5. Stress corrosion

The term "stress cracking" (SSC) refers to conditions that occur when static tensile stress, a corrosive environment, and, in certain instances, a structural condition that causes the component to fail prematurely are all present [32]. Tensile stresses may be the result of residual stresses, thermal stresses, or external forces [29]. Since the SCC process is composed of corrosion and stress, failure behavior is complicated and multi-scale [33].

3.1.6. Selective leaching corrosion

The corrosion process known as selective leaching, which is also known as dealloying or separating corrosion, is a process that involves removing a highly reactive metal from an alloy in order to leave behind a weak, porous layer of the more noble metal. The metal becomes spongy and porous, resulting in a significant reduction in its strength, hardness, and ductility [29].

3.1.7. Fretting corrosion

Fretting corrosion occurs in metal alloys that form a passive layer. The abrasive or wear action may erode the film, leaving an exposed metal surface [34]. As a consequence of this, the newly formed metallic surfaces as well as the metallic particles undergo oxidation. The surface debris is adversely impacted by functioning as an abrasive agent during future micromotions [30].

4. Plasma sputtering coating technique

Many medical devices are constructed of metal, which is susceptible to corrosion, wear, and rejection by the human body during use. Coatings can enhance the surface qualities of devices and prolong their lifespan [35]. The coating is a very thin and useful layer ranging from a few nanometers to several micrometers in thickness [36]. The process of forming thin films is known as deposition. There are many physical and chemical deposition methods available [37].

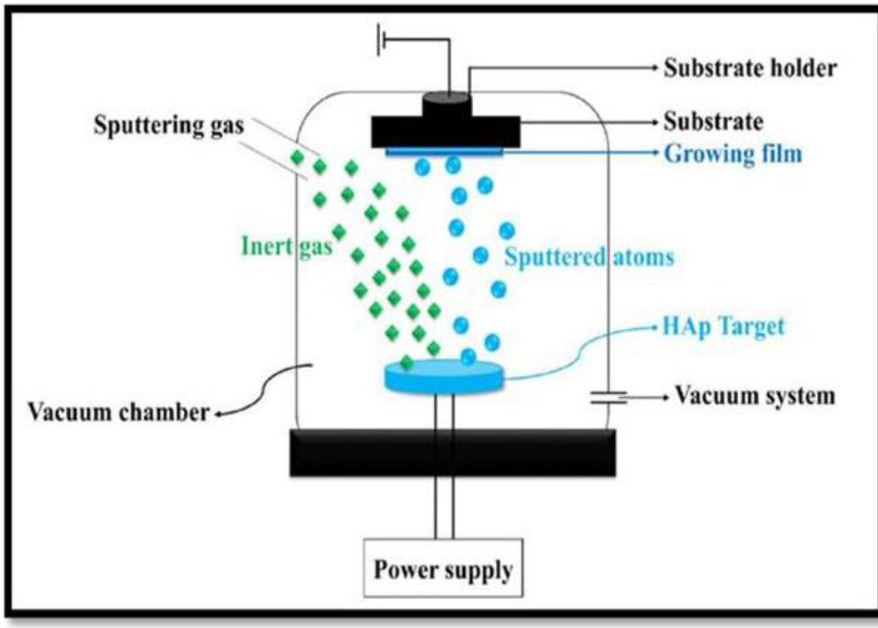

Fig. 3. A schematic illustration of plasma sputtering coating process for deposition of HAp coatings [77].

Physical vapor deposition (PVD) is a technique that entails the transition of substances from their solid state to a vapor state and then back to their solid state, leading to the formation of a thin coating on a substrate [38]. PVD is a remarkable vacuum coating method for improving wear and corrosion resistance [39] without altering the biomechanical characteristics of the base material, and coating is compact and homogeneous [40]. Evaporation and sputtering are the predominant gaseous surface coating techniques associated with the PVD process [41]. Sputtering is (PVD) technique for coating, wherein the target material is blasted with ionized gas molecules e.g. He or Ar, induces the "sputtering" of atoms into the plasma [42], as illustrated in (Fig. 3).

When the target material's outer atoms are energetic enough to break their bonds with adjacent atoms, they scatter outward. The sputtered particles advance towards the substrate surface positioned on the substrate holder, within an ultra-clean environment created by a vacuum pump [43].

Before the application of the coating, the substrate is generally situated within a vacuum cylinder filled with an inert gas. Upon the application of a negative charge to the target substance, it operates as a cathode and releases electrons into the surrounding environment. The electrons that are not bonded interact with the electrons that are negatively charged and that are surrounding the gas atoms. The ions that are produced as a result of the ejection of electrons from a gas are positively charged and possess a significant amount of energy. The source material is then attracted to these ions, which clash at such elevated velocity that they remove particles as little as atoms from the target [44]. In a vacuum cylinder, the target is positioned in opposition to the substrates in a gas, typically argon, with potentially reactive gases (O_2, N_2, etc.), a precursor gas is subjected to a significant potential difference. Due to its affordability and widespread compatibility with substances relevant to engineering, argon is employed in the majority of applications. Ionized argon atoms are responsible for the ion bombardment of the target when the target is powered negatively, which is normally between 0.5 and 5 kV [45].

Sputtering is quite versatile since it may deposit a wide variety of materials, such as metals, semiconductors, and insulators [46]. The sputtering technique is primarily employed to deposit metal and oxide layers by adjusting the surface roughness and crystalline form [36]. The rate of film deposition is influenced by a number of sputtering parameters. The rate of film deposition is influenced by a number of sputtering parameters. Among the sputtering parameters are the following: the voltage that is applied, the sputter yield, the kind of gas utilized, the target material that is used, the substrate type that the coating is going to be deposited on, the operating pressure inside the chamber, the power, the temperature of both the substrate and system, the angle of incidence of bombardment, and the distance between the substrate and the target. It is necessary to have these criteria to manufacture thin films that have the desired thickness and qualities. In addition to chemical characteristics, physical features, thermal characteristics, and electrical functions, these attributes also include optical properties [47]. The introduction of high voltage to the target material produces a highly intense plasma, which subsequently liberates atoms or ions from the target's surface. To achieve uniform coating thickness, these particles are subsequently placed onto the circulating substrate within a deposition chamber that functions under an extremely high vacuum [48].

Dave et al. [49] and Malik et al. [50] both concentrated on the fabrication of zinc oxide coatings on glass via various sputtering processes. The argon-to-oxygen gas mixture was manipulated during the deposition process in the first investigation that was carried out by Dave and colleagues. The findings of this study indicated that a reduction in the oxygen gas flow rate and an increase in the argon gas flow rate resulted in enhancements in the average crystallite size, surface roughness, and thickness of the zinc oxide coating. On the other hand, Malik et al. made adjustments to the sputtering voltage and operating pressure, and they found that an increase in operating pressure led to an increase in crystallite dimensions as well as an improvement in crystallinity.

Pathote et al. [42] employed DC magnetron sputtering to apply a coating with multiple layers of tantalum to austenitic stainless steel type 316L, with a thickness of 1.504 μm, 3.893 μm, and 6.083 μm, respectively. The corrosion performances of the coated and uncoated specimens were assessed in simulated body fluid by potentiodynamic (PD) polarization and electrochemical impedance spectroscopy (EIS) at 37 $\pm$ 1 °C following stabilization at open circuit potential. Surface characterization was conducted via scanning electron microscopy (SEM) to evaluate morphology and corrosion damage, and X-ray photoelectron spectroscopy (XPS) to ascertain chemical contents. The findings indicated that the sample coated for 60 minutes had the optimal corrosion resistance, characterized by the lowest corrosion rate of 0.0047 mm/year and the most advantageous impedance response. SEM images revealed a reduced number of corrosion pits on all Ta-coated samples relative to the uncoated substrate, while XPS demonstrated the development of a persistent Ta^{4+} oxide layer and good adhesion between the coating and substrate. The Ta coating markedly enhanced the corrosion resistance of 316L stainless steel by creating a deep, protective oxide layer. As shown in Table 1, many studies have employed the sputtering technique to coat dental alloys.

The process of sputtering has several advantages [51]:

1. It is possible to apply a coating that is highly pure and homogenous in wide regions while maintaining a strong adherence to the substrate.
2. Sputtering allows for easy fabrication of substances with high melting points.
3. The deposited films exhibit a composition identical to that of the original substances.
4. Even distribution of the deposited coat results in uniform thickness.
5. Also, the substrate with a complex configuration can be coated with this technique easily, producing a uniform thickness coat.
6. The sputtering process is applicable for ultrahigh vacuum applications.
7. The sputtering sources exhibit compatibility with reactive gases, such as oxygen [51].
8. Reduces residual strains on the substrate by depositing thin films at low or moderate temperatures.
9. One benefit of a vacuum sputtering machine is its capacity to cleanse substrates [41].
10. Sputtering enables deposition at temperatures below 50 °C, hence reducing the harmful effects on the substrate [44]. This is especially crucial when two materials, produced as neighboring layers, are susceptible to mutual interdiffusion or adverse chemical interactions.
11. It is possible to sequentially deposit multiple materials to create well-defined multilayer systems [52].

Two common kinds of sputtering processes are as follows: [43]

a. Direct current (DC) sputtering process.
b. Radiofrequency (RF) sputtering process.

The first method is reliant on direct current power, which is typically employed with electrically conductive target materials. For the majority of dielectric materials, radio frequency power is employed in RF sputtering [41]. The target material is subjected to a constant voltage during DC sputtering, which results in the production of a uniform plasma for the deposition process [53]. During RF magnetron sputtering, the utilization of a radiofrequency source to generate an oscillating electric field within the working space enhances plasma ionization, thereby improving the deposition rate [54].

Table 1. Studies discuss the sputtering coating technique in dentistry.

Year	Cite	Title	Aim	Method	Conclusion
2015	[55]	Tantalum Nitride-decorated Titanium with enhanced resistance to microbiologically induced corrosion and mechanical property for dental applications	Assess a titanium substrate coated with tantalum nitride (TaN) for improved mechanical features and resistance to microbiologically promoted corrosion (MIC) for use in dentistry.	TaN coatings were applied to pure titanium through the process of magnetron sputtering. The coatings were characterized for their microstructure and composition using (SEM) and (XPS), and mechanical features, including hardness and elastic modulus, were assessed. The samples were also tested for corrosion resistance using potentiodynamic polarization and (EIS) in artificial saliva containing bacteria. Additionally, biofilm formation and antibacterial performance were assessed.	Compared to pure Ti and TiN coating, TaN coating offered the best protection for Ti in both artificial saliva and bacteria-containing artificial saliva, greatly increased MIC resistance, and had a good binding strength. According to mechanical tests, the TaN layer improved the hardness and elastic modulus of the Ti alloy. TaN-decorated Ti demonstrated strong in vitro antimicrobial properties towards various bacteria, including S. mutans, A. viscosus, and P. gingivalis, following a 14-day incubation period.
2015	[56]	Determination of structural, mechanical and corrosion properties of Nb_2O_5 and $(Nb_yCu_{1-y})O_x$ thin films deposited on Ti6Al4V alloy substrates for dental implant applications	This work aims to demonstrate that copper-doped niobium pentoxide thin films can be applied as a layer to improve the mechanical characteristics of a titanium alloy's surface and protect it against corrosion.	Using the magnetron sputtering method, a Ti6Al4V alloy was covered with a pure layer of niobia and a niobia layer that included copper. XRD, XPS, SEM, and AFM investigations assessed the thin films' physicochemical properties. Nanoindentation and steel wool tests measured nanohardness, Young's modulus, and abrasion resistance. Analysis of voltammetric curves determined coating corrosion properties.	Pure Nb_2O_5 had a hardness of 8.64 GPa. The results indicate that a coat with a decreased hardness of 7.79 GPa (for niobia with 17 at.% Cu) and 7.75 GPa (for niobia with 25 at.% Cu) was generated upon the addition of copper to pure niobia. When copper was added to Nb_2O_5 film in a corrosion test, the corrosion resistance increased, the corrosion currents significantly decreased. The Ti6Al4V sample treated with a thin coating of $(Nb_{0.75}Cu_{0.25})O_x$ had the best corrosion characteristics.
2016	[57]	Corrosion and wear behaviors of a reactive sputter deposited Ta_2O_5 nanoceramic coating	The goals of this investigation are to enhance the corrosion resistance and wear of Ti-6Al-4V following its coating with a novel Ta_2O_5 material.	Reactive sputter deposition was employed to deposit a Ta_2O_5 coating onto a Ti6Al4V alloy. The microstructure of the novel thin film was analyzed using energy-dispersive X-ray spectroscopy (EDS), transmission electron microscopy (TEM), (XRD), (XPS), and (SEM). To assess the coating's performance at room temperature, both electrochemical analyses and dry sliding wear experiments were implemented.	Under the same loading circumstance, the specific wear rates of the coating were discovered to be two orders of magnitude less than those of Ti6Al4V. The results indicated that the corrosion resistance of the -Ta_2O_5 nanoceramic coating was superior to that of the Ti6Al4V alloy in a 3.5 wt.% sodium chloride solution.
2017	[58]	ZrCuFeAlAg thin film metallic glass for potential dental applications	The primary goal of this study is to enhance the unsatisfactory tribological performance of titanium alloys utilized in dentistry through the application of a nickel-free $Zr_{60.14}Cu_{22.31}Fe_{4.85}Al_{9.7}Ag_3$ thin film metallic glass (TFMG) coating.	Single target magnetron sputtering was used to coat the biomedical Ti6Al4V substrate with the TFMGs. The fretting resistance was evaluated using a reciprocating tribo-tester with a Si_3N_4 counterpart in both air and artificial saliva. The electrochemical features of TFMG-coated Ti6Al4V samples was evaluated using electrochemical polarization and (EIS) in artificial saliva. The biocompatibility of TFMG was studied via in vitro experiments and compared to that of a titanium-based alloy.	This TFMG has 1.8–2.8 times better fretting resistance than Ti6Al4V in various tribological conditions, reduced biocorrosion, and improved passive film. Laboratory assessment of cytotoxicity indicates that the TFMG shows no signs of cytotoxicity. The present nickel-free zirconium-based TFMG is expected to improve the durability and performance of biomedical implants or appliances used in applications in dentistry.

(Continued)

Table 1. Studies discuss the sputtering coating technique in dentistry.

Year	Cite	Title	Aim	Method	Conclusion
2019	[59]	Biocompatibility study of multi-layered hydroxyapatite coatings synthesized on Ti-6Al-4V alloys by RF magnetron sputtering for prosthetic-orthopaedic implant applications	The purpose of this work was to investigate the triple layered coatings of titanium oxide, aluminum oxide, and hydroxyapatite that were coated onto Ti-based alloys using the magnetron sputtering process in order to improve the surface biocompatibility and corrosion resistance characteristics.	The RF magnetron sputtering technique was utilized in order to deposit coatings consisting of triple layers of hydroxyapatite, aluminum oxide, and titanium oxide onto substrates made of Ti-6Al-4V alloy. The coatings were sequentially applied with TiO_2 as the base layer, followed by Al_2O_3, and topped with (HAp). After deposition, coated samples were immersed in SBF. Characterization techniques included (XRD), and (XPS), (EIS) was employed to assess the corrosion characteristics of the protective coatings.	The hydroxyapatite layers substantially enhanced the surface's biocompatibility, while titanium oxide and aluminum oxide layers augmented the ability to withstand corrosion of the substrate material by preventing the ingress of active ions from the surroundings onto the surface of Ti6Al4V alloys.
2019	[60]	Surface characterization and corrosion resistance of Boron Nitride coated Titanium dental implants	Through the use of boron nitride (BN) coating, the purpose of this research was to improve the surface features of titanium dental implants as well as their resistance to corrosion.	The BN layer was deposited on pretreated implant surfaces, such as sandblasted, large-grit, acid-etched (SLA) titanium surfaces, using an RF magnetron sputtering technique. SEM, EDS, and XPS were employed to examine the surface morphology and chemical content, and the ability to resist corrosion in artificial saliva was evaluated.	The results revealed that BN coating significantly altered the surface topography by increasing micro-roughness through the creation of additional peaks and pores on the sponge-like SLA surface. The boron-to-nitrogen ratio ranged from 0.8 to 1.6, and no weight loss was observed for the BN-coated SLA implants during corrosion testing. These findings indicate that BN can be successfully deposited on titanium implants, improving their surface properties and corrosion behavior, particularly for SLA-type surfaces, thereby enhancing their potential for dental implant applications.
2020	[61]	Evaluation the corrosion resistance of Pt thin films for medical applications	Platinum (Pt) nanostructured coated films are created using the magnetron sputtering process to enhance the localized resistance to corrosion of Ni-Cr alloy surfaces when exposed to artificial saliva.	Using the magnetron sputtering process (Pt.), coatings with thicknesses of 17 nm and 34 nm have been produced. Before creating Pt thin films on Ni-Cr alloy surfaces using DC, a layer of 5 nm of titanium (Ti) is applied using RF power. The study looked at how well the materials resist localized corrosion in an artifical saliva solution at 37 ± 1°C using open circuit potential, Tafel extrapolation, and cyclic polarization methods.	The outcome demonstrated that uniform and crack-free Pt thin films with nanostructured morphology were successfully deposited, and they considerably increased localized corrosion resistance of the Ni-Cr samples in a simulated oral environment.
2021	[62]	Sputtered crystalline TiO_2 film drives improved surface properties of titanium-based biomedical implants	In order to elucidate the surface and electrochemical properties, as well as the phenomena of protein adsorption and apatite layer formation on titanium-based implant materials, a range of crystalline phases within titanium oxide coatings was developed.	The deposition conditions for two crystalline phases of TiO_2 (rutile and anatase) were created and subsequently formed on (cpTi) using magnetron sputtering to create the following groups: M-TiO_2 (mixture of anatase and rutile), R-TiO_2 (rutile), A-TiO_2 (anatase). Untreated cpTi served as a control group.	The mixture of rutile and anatase structures to produce TiO_2 coating is a potential approach to enhance the attributes of biomedical implants, including improved corrosion resistance, increased protein adsorption, biological action, and non-cytotoxicity.

(Continued)

Table 1. Studies discuss the sputtering coating technique in dentistry.

Year	Cite	Title	Aim	Method	Conclusion
2021	[63]	Corrosion resistance and antibacterial activity of Ti-N-O coatings deposited on dental titanium alloy	This study attempted to improve the durability against corrosion and antibacterial features of the Ti6Al4V dental alloy through the application of Ti-N-O and TiN layers with varying chemical concentrations via the (PVD) technique.	The phase structure, surface morphological characteristics, and elemental concentration of the Ti-N-O coatings were examined using XRD, XPS, and SEM techniques. The electrochemical behavior activity of Ti-N-O coatings in fluoride-containing and acidic artificial saliva was studied. An in the laboratory test was performed to determine the antibacterial potential of the coated Ti alloy.	The findings show that the phase compositions of Ti-N-O coatings progressively change from TiN to TiN_xO_y, Ti_2O_3, TiO_2, and Ti_3O_5 as the flow rate of O_2 in the reaction atmosphere rises. The passivation properties of Ti-N-O coatings are remarkable. Ti-N-O coating exhibits higher corrosion resistance than TiN coating in acid (pH = 5.2) solution with a corrosion current density of only 6.0×10^{-8} A/cm^2 at a 2:1 flow rate ratio of N_2 and O_2. Ti-N-O coating has a 90% antibacterial rate against Staphylococcus aureus at a 1:1 N_2 and O_2 flow rate.
2021	[64]	Performance of reactively co-sputtered titanium chromium nitride films in artificial saliva: Corrosion protection and reduction in the release of potentially toxic elements	This study aimed to improve the corrosion-resistant property of 304 stainless steel and reduce the release of potentially hazardous elements, particularly chromium, by coating titanium-chromium-nitride films.	Reactive co-sputtering deposited TiCrN films. Next, the coatings were annealed at 400 and 700°C in an air environment. Ultraviolet-visible spectroscopy, inductively coupled plasma mass spectrometry (ICP-OES), potentiodynamic polarization curves, field emission scanning electron microscopy (FESEM,EDS) and (AFM) were the last techniques used to characterize the samples.	The findings indicated that the film subjected to annealing at 400 °C exhibited the most favorable short-term corrosion resistance,while the as-deposited film performed best after long-term exposure. When compared to uncoated SS304, all coated samples showed better corrosion protection, and over an extended period of exposure, they can decrease chromium emission by over 67%.
2023	[65]	In vitro cytotoxicity, corrosion and antibacterial efficiencies of Zn doped hydroxyapatite coated Ti based implant materials	The objective of this research is to apply zinc-doped hydroxyapatite (Zn-HAp) to Ti6Al4V alloy, which is utilized in dental and orthopedic implants, in order to improve its biological and electrochemical performance.	The surfaces of the Ti6Al4V alloy were changed using the RF magnetron sputtering process and covered with hydroxyapatite mixed with zinc.	The resulting coating showed improved corrosion resistance, antimicrobial efficacy against Escherichia coli (E. coli) germs, and osteointegration. The coating was also extremely stable and had a highly crystalline structure.
2023	[66]	Mechanical, tribological and electrochemical behavior of Zr-based ceramic thin films for dental implants	This work examined the mechanical, tribological, and corrosion properties of magnetron sputter-deposited zirconium, zirconium nitride, and zirconium nitride/zirconium coatings on AISI 304 stainless steel substrates (SS 304) in simulated physiological liquids (blood plasma and saliva).	Both experimental with computational approaches were employed to assess performance in simulated physiological environments, including artificial saliva and blood plasma. Structural and compositional analyses were correlated with tests for plastic deformation resistance, wear, and electrochemical corrosion using potentiodynamic techniques	The results showed that the ZrN/Zr multilayer coating exhibited superior resistance to abrasion and corrosion, attributed to its ceramic-metal configuration. Computational modeling using Density Functional Theory (DFT) further supported these findings by revealing high energy barriers for electron transfer during wear, as well as strong adsorption of urea molecules on the ZrN surface, which promotes the formation of passivating protective layers.

(Continued)

Table 1. Studies discuss the sputtering coating technique in dentistry.

Year	Cite	Title	Aim	Method	Conclusion
2024	[67]	A comparative study of TiO_2, Ta_2O_5 and Nb_2O_5 coated Ti6Al4V titanium alloy for biomedical applications	The study aims to compare the performance of three different ceramic oxide coatings TiO_2, Ta_2O_5, and Nb_2O_5 on Ti6Al4V alloy for biomedical purposes. The goal is to evaluate their effectiveness in enhancing resistance to corrosion, mechanical characteristics, and biocompatibility of the base alloy and to determine which coating offers the best overall performance for potential use in medical implants.	In this work, radio frequency sputtering was used to produce thin layers of Ta_2O_5, Nb_2O_5, and TiO_2 on Ti6Al4V alloy. Scratching, nanoindentation, wear and friction, potentiodynamic polarization, and cell culture assays were among the tests used to compare their characteristics.	The results showed that all coatings improved the alloy's properties, but TiO_2 performed the best overall, offering the highest adhesion strength, superior wear and corrosion resistance, and the greatest cell compatibility.
2024	[68]	Corrosion behavior, metal ions release and wear resistance of TiN coating deposited on SLM CoCrMo alloy by magnetron sputtering	This investigation focused on improving the surface characteristics of CoCrMo alloy fabricated through selective laser melting by employing a titanium nitride coating via the magnetron sputtering method.	The methodology involved structural and morphological analysis of the TiN coating by (XRD) and (SEM), Subsequent procedures included electrochemical corrosion testing, analysis of ion release, and evaluation of resistance to wear under various normal loads.	Electrochemical measurements revealed a decrease in corrosion current density from 19.1n A/cm^2 to 8.12nA/cm^2 after TiN coating, indicating moderate improvement in corrosion resistance. The coating effectively reduced the release of Co, Cr, and Mo ions in short-term immersion but lost. Wear resistance was enhanced only under low-load conditions (5N), while higher loads (10 and 30N) led to coating failure. mild service conditions.
2025	[69]	The influence of Si(C,N) layer composition on the corrosion of NiCr prosthetic alloy	This study evaluates the adhesion and corrosion resistance of a reactive magnetron sputter-coated Ni-Cr dental alloy with a Si(C,N) film..	In order to deposit Si(C,N) coatings onto the surface of a NiCr dental alloy, the reactive magnetron sputtering technology was employed. Four unique changes in the carbon-to-nitrogen percentage were analyzed./	The utilization of Si(C,N) coatings can improve the biological compatibility and long-term safety of NiCr-based implants, which can decrease the discharge of allergenic Ni^{2+} ions. The corrosion protection of Specimen D (39.6% C, 25.2% N) was the most effective, as evidenced by the highest Rp value, lowest corrosion current density, and lowest corrosion rate. This demonstrates an appropriate balance of carbon and nitrogen content.
2025	[70]	Magnetron sputtered ß-Ti coatings for biomedical application: A HiPIMS approach to improve corrosion resistance and mechanical behavior	Using magnetron sputtering to deposit a thin layer of a β-Ti alloy, the study intends to enhance the surface performance of (CP-Ti) produced by powder metallurgy.	Using the same power level (250 W), pulsed DC and high-power impulse magnetron sputtering (HiPIMS) were applied both with and without a substrate bias of -60 V. Coatings were deposited on silicon substrates and Ti specimens, and characterized by(XRD), nanoindentation, wettability tests, (XPS), and (EIS).	The results showed that all coatings exhibited a significantly reduced Young's modulus ($\leq$ 80 GPa), lowering the risk of stress-shielding effects in implants. Although the hardness values (4.1–4.7 GPa) were slightly lower than that of the Ti substrate, XPS analysis confirmed the presence of a stable oxide passivation layer (TiO_2, Nb_2O_5, ZrO_2), contributing to excellent corrosion resistance. Among the methods, HiPIMS coatings provided the best combination of mechanical integrity and corrosion protection .These findings highlight the promise of TNZT thin films, especially those deposited by HiPIMS, for biomedical implant applications

5. Discussion

Over the past decade (2015–2025), many research investigations have focused on improving the corrosion resistance of metallic materials employed for dental applications. These efforts have primarily targeted alloys such as Ni-Cr and Co-Cr, which are commonly used in dental prosthetics. However, a significant portion of the research has concentrated on titanium alloys, particularly Ti-based materials used in dental implants. This is largely due to titanium's critical role in clinical performance, not only for its corrosion resistance but also for its influence on other key properties, such as mechanical strength, biocompatibility, and antibacterial activity. The consistent trend across these studies highlights the importance of surface modification, especially via sputtering deposition, as a strategic approach to enhance the long-term sustainability and safety of dental materials in the oral environment.

Alloys in the mouth are subject to a wide range of conditions, including mechanical stresses, pH, bacterial microflora, salivary characteristics, and nutrition [71]. Corrosion of metal is caused by the aggressive action of the oral environment and other fluids [72]. The biocompatibility and functional appropriateness as well as the durability of dental restorations, are directly affected by the corrosion resistance of dental alloys [73]. The Ti-6Al-4V alloy comprises aluminum, vanadium, and other metals; the risk of corrosion impairs its mechanical qualities and leads to complications such as implant fractures [74].

Surface modification technology enhances titanium's biocompatibility, antimicrobial, and anti-wear qualities while maintaining its biomechanical superiority [63]. A multitude of coating processes exists, reflecting a wide range of uses and requirements across many different fields [75]. Sputtering is a highly effective method for the creation of thin films that have a wide range of applications [76]. During the procedure, several sputtering parameters are regulated to achieve an optimal deposition rate and the desired thickness of coating. The optimal thickness will yield the necessary particular qualities [47].

Despite these advancements, certain limitations remain. The lack of standardized testing conditions, such as variation in pH, immersion time, and electrolyte composition, makes directly comparing the results of various studies challenging. Moreover, the majority of investigations have been conducted in vitro, with limited in vivo or clinical validation of the long-term performance of sputtered coatings under real oral conditions.

6. Conclusion

To improve the surface features of the restoration, such as corrosion and wear resistance, and to extend their life, sputtering is an excellent process for creating and depositing diverse thin films on different dental metals with variable specifications. The application of resistant corrosion coatings on surfaces is a prevalent and economical method to enhance corrosion resistance in metallic constructions.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical approvals

Not applicable.

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