Implant Material Coating Technique: Physical Vapor Deposition

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ABSTRACT

This review provides a serious analysis of the physical vapor deposition magnetron sputtering (PVDMS) technique that has been applied to coating implants with ion substituted based materials and explains the impact of PVDMS processing variables on the surface morphology and crystal structure of ion-substituted thin coatings. These factors include discharge power, bias voltage, deposition time, substrate temperature, and post-heat treatment. It is elucidated and summarized by searching different scholarly published articles and PubMed indexed researches in addition to Cochrane library and Google scholar website from1970 till 2021.

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INTRODUCTION

Medical devices like artificial joints, screws ,bone plates, and other biomedical implants which used in surgery are frequently made of metallic biomaterials like commercially pure titanium (CPTi) and certain of its alloys. But because of their rapid erosion in the biological environment, which causes metal ions to be released and the accumulation of waste product ,bare Ti-based alloy implants have limits [1]. Without surface modification, metallic implants may get engulfed by fibrous tissue, extending the healing process and increasing the risk of loosening in implant and eventually early implantation failure [2]. The surface of biomaterials have been coated with homogeneous layers using a variety of approaches, such as: Plasma spraying [3], sol-gel coating [4], electrophoretic deposition [5], micro arc oxidation [6], chemical vapor deposition [7], ion beam assisted deposition [8], pulsed laser deposition [9] and physical vapor deposition magnetron sputtering [10]. Recent developments in the PVDMS process have shown that it is an affordable, straightforward, ecologically friendly way to create Ca-P coatings with ions as substitutes on titanium with related alloys [11]. On other hand, Disadvantages of physical vapor deposition magnetron sputtering as follows: Time consuming, Low deposition rate, and Capacity limited for large diameter of wafer.

CLASSIFICATION OF DENTAL IMPLANTS

There are three types of dental implants:
1) Depending on where they are placed within the tissues: Endossus, Subperiosteal, Transosteal.
2) Depending on the materials utilized**:**

- Metallic implants: as an example, Titanium, Titanium alloy, and Cobalt Chromium Molybednum alloy.
- Non- metallic implants – like Ceramics, Polyetheretherketone (PEEK),….. etc.

3)Depending On Their Reaction With Bone:

1. Bioactive implants – Hydroxyapatite. 2.Bio-inert implants –as an example, metals [12].

IMPLANT REQUIRMENTS AND DESIGN

Osseointegration was improved in order to increase the longevity of the implants. Following variables are crucial : Biomaterials composition, Biomechanical factors, Implant width, length and geometry, Surface features, Health status of the patient, bone quality and surgical procedure [13].

SURFACE CHARACTERISTICS

Research has displayed that osteoblast cells stick to rough surfaces more quickly than to smooth surfaces**.** Chemical modifications can be divided into two categories. 1. Addition of inorganic phases (e.g., hydroxyapatite or calcium phosphates). 2. Addition of organic phases (growth factors).

CLASSIFICATION OF DETNTAL IMPLANT MATERIAL BIOCOMPATIBILITY

Biomaterials can be classified based on their level of biocompatibility as being:

1) Bioactive, 2) Biodegradable, 3) Bioinert, and 4) Biotolerant.

PHYSICAL VAPOR DEPOSITION (PVD) METHOD

PVD coatings have the ability to act as a barrier between the substrate's metal surface and the corrosive environment because corrosion-inhibiting chemicals are doped into the coating components. This protection is provided to the substrate's surface. The covering must be homogeneous, pore-free, self-healing, and promote the connection between metallic implants and bone tissue in order to offer adequate protection.(14).PVD methods are frequently divided into two groups: Magnetron sputtering and evaporation techniques. By modifying processing variables such substrate temperature, post-heat treatment, discharge power, bias voltage, deposition time, Ca and P ions may be replaced on the surface of Ti alloys using the PVDMS technique [15]

DEVICED USED FOR PVD (PARTS AND THE PARAMETERS)

In PVD procedures, the target material is transformed into atomic particles by a thermal physical process of release or collision, which are then guided onto the substrates under gaseous plasma conditions in a vacuum environment, creating a physical coating by con densation or the accumulation of projected ato ms.The PVD reactors consist of two electrodes linked to a high voltage power source and a vacuum chamber[16]. In sputtering procedures, a magnetron is positioned close to the target. Then, between the target and the substrate, a high voltage is applied in the magnetron's direction, accelerating an inert gas that is delivered into the vacuum chamber. This causes the freedom of atomic-sized particles from the target. Gas ions that have touched their target and travelled to the substrate to form a solid thin layer are responsible for projecting these particles as a result of the kinetic energy they transferred [16]**.** Keep in mind that the system vaporizes any substance in proportion to the strength of the e-beam. Particles are released once the material is heated to a high vapour pressure by blasting electrons in a high vacuum. The discharged particles of atomic size then collide with the gas molecules introduced into the reactor**,** with the aim of fast-tracking the particles, by creating plasma. Through the deposition chamber, this plasma travels. The adherence of the formed film to the substrate is improved by successively squeezed layers being deposited [16-17].

Ca-P AND ION-SUBSTITUTED Ca-P COATING VIA PVDMS

It is a kinetically regulated process in which ions from positive inert gas ions hit the source targets. In the 1970s, PVD magnetron sputtering was first identified. In industrial processes that commonly use argon gas, plasma is created when an electrical charge ignites between the substrate (anode) and the target (cathode).The catholic region's departing electrons are enhanced by the electric field before striking the target's surface.

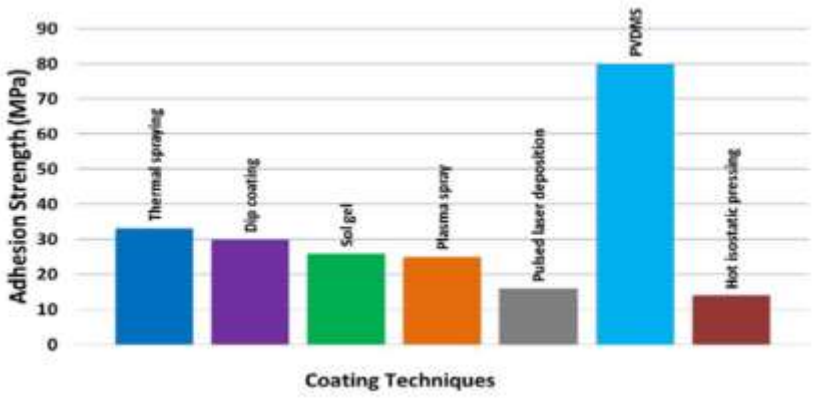
Ca-P AND ION SUBSTITUTED Ca-P BASED COATING MORPHOLOGY, CRYSTALLINITY, AND Ca/P RATIO

During the PVDMS process, a variety of processing factors control the shape of both pure Ca-P and Ca-P with ion substitutions on metallic implant surfaces. Power (W), post-annealing conditions, sputtering temperature (C), duration (min), bias voltage (V), and radio frequency (RF)are among the processing parameters. The shape of a biomaterial's surface has a significant impact on its

performance[18]. In general, PVDMS can provide coatings of great quality. However, depending on the deposition settings and the sputtering technology, the structure of coatings may differ from the structure of the bulk target [19].The considerable loss of P ions or the favoured installation of Ca ions is likely caused by differences in the Ca/P ratio between the HA targets and the sputtered coatings**,** which may be re-sputtered out of the forming layers by incoming ions or driven off before attainment on the substrate surface. According to reports, raising the annealing temperature resulted in an increase in the Ca/P ratios [20] reported the impact of bias voltage on the coating's crystallinity and Ca/P ratio. Calcium was found to be formed in the plasma as positively charged ions (Ca+ and Ca++) and radicals (CaO+), also was noticed, greater Ca/P ratios will occur from higher fluxes of CaO+ cations onto the surface and reduced access of $(PO_4)_3$ anions to the substrate surface due to increasing negative substrate bias [15].

Ca-P COATING USES AND ITS ADHESION STRENGTH

There are many coating techniques that can produce different degrees of adhesion strengthwith Ca-P coatings.



BIOLOGICAL ANALYSIS OF HA AND ION-SUBSTITUTED-HA PVDMS COATING

Pure HA is generally unsolvable when in interaction with human fluids and is resistant to resorption. Consequently, it is advised to use ion-substituted Ca-P coatings that have properties similar to those of bone minerals. Human mineralized tissues may substitute strontium (Sr), manganese (Mn), calcium (Ca), phosphates $(PO4)_3$, and magnesium (Mg) for silicates (SiO4) [21].

HYDROXYAPATITE (HA)

Surmeneva et al., 2014 [22]analyzed the HA coatings in vitro using dental pulp stem (DPS) cells. Increased cell attachment and dispersion were seen on the Ca-P coated surface regions compared to the uncoated Ti surface, showing considerable cell proliferation and matrix production.

STRONTIUM HYDROXYAPATITE (Sr-HA)

By reducing the number of active osteoclasts and increasing the pool of active osteoblasts, the addition of a Sr element to a drug may reduce bone resorption(23).Due to the enlarged ionic radius of Sr and the resulting lattice expansion, HA coatings with higher percentages of Sr content, such as the annealed Sr-HA surface, are more likely to dissolve in physiological environments [24].The lattice parameters rise as a result, and the Ca site is regarded to be the favoured site for Sr replacement[25].These chemicals enhance osteoblast activity (proliferation), reduce osteoclast activity, and increase cell differentiation, all of which are crucial both in vitro and in vivo [26].

SILICON HYDROXYAPATITE (Si-HA)

Si has substantial effects on HA coatings in that it reduces the size of the HA crystal, encourages a creation of amorphous phases, enhances its solubility, boosts the surface's electronegative properties, and strengthens adhesion[27].Constructions made of crystalline as well as amorphous materials were implanted, gradually resorbed inside the body, and caused the release of Ca and P ions, which stimulated the production of new bone. All samples displayed quick cell attachment on the surface

area and the cells covered the whole HA-coated surface, exhibiting no obvious toxicity.Si-HA coatings produced by PVDMS have the capacity to produce Ca-P that contains carbonate and may be a suitable alternative for hard tissue.

MAGNESIUM HYDROZYAPATITE (Mg-HA)

High cell survivability and osteoblast adhesion were seen in the biological evaluation of the sputtered Mg-HA coating, however there was no discernible change in cell connection compared to HA.Additionally, it was discovered that the Mg-HA coating was extremely amorphous in form and triggered rapid breakdown, producing biological reactions that were comparable to those of HA coatings [(28)].

FLUORINE HYDROXYAPATITE (F-HA)

Before F-HA deposition, the substrates were heated to various high temperatures of 100, 200, and 300°C to generate a crystalline coating. Pre-deposition heating at 300 C may achieveF-HA thin coatings with an appropriate crystallinity[29].

SILVER HYDROXYAPATITE (Ag-HA)

The concentration of Ag was thought to be significantly influenced by the PVDMS deposition settings. According to a paper, HA coatings can improve antibacterial capabilities while exhibiting little cytotoxicity due to the quantity of liberated silver ions (up to 3 weight percent)[30].Without forming the stoichiometric HA phases, it was shown the insertion of Ag ions (2.1 wt%) was sufficient to induce an antifungal action in the HA coating.It was discovered that HA with the addition of Ag (0.7wt%) enhanced defence against bacterial violence. Such as Salmonella typhi, Streptococcus pyogenes, and Staphylococcus aureus, that are without affecting their microstructural, microchemical, or anticorrosive capabilities.

CARBONATE HYDROXYAPATITE (C-HA)

Sputtered C-HA coatings demonstrated great osteoblast viability and proliferation without harmful effects on bone cells [31].

CONCLUSIONS

1. Researchers have identified a number of controlling factors that directly affect the chemical and physical characteristics of ion-substituted Ca-P coatings produced by PVDMS.These factors include substrate temperature, post-deposition annealing, deposition time, bias voltage, and discharge power.PVDMS may be utilized to create thin coatings that are dense, uniform, and have strong adhesion strengths.
2. This method may be utilized to create nanostructured Ca-P coatings with improved biocompatibility and corrosion resistance on polymericbiodegradable and biomaterials metals like Mg-based alloys. These characteristics hold promise for expanding the range of therapeutic applications in the upcoming years. Also, PVDMS enables the insertion of medicinal ions and a near replication of bioapatite properties, including strong adhesion strength.

Conflict of Interest : None

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