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Solution for Environmentally Friendly Silver Surface Magnetron Sputtering Color Titanium Film Layer Technology

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ABSTRACT

Silver is an elegant white precious metal, but it is easily oxidized by O_3, SO_2, and H_2S in the air, turning yellow or dark, which affects its decorative effect. The existing silver coating, primarily prepared through the electroplating process, poses serious environmental pollution problems. It is necessary to seek new, green, and environmentally friendly coating processes while also enhancing the color palette of silver jewelry coatings. Titanium film layers were deposited on Ag925 and Ag999 surfaces using magnetron sputtering coating technology. The effects of sputtering time, substrate surface state, reaction gas type and time, and film thickness on the color of the film layers were studied, and the anti discoloration performance of the obtained film layers under the optimal process was tested. The experimental results show that when the sputtering time varies from 5 to 10 minutes, injecting argon, oxygen, and nitrogen into the coating chamber yields rich colors such as purple with a red tint, blue, yellow green, yellowish purple, and blue purple. The precise control of gas injection time has a significant impact on the color of the film layer. In terms of anti tarnish performance, the film showed good stability in the artificial sweat immersion test. From an environmental perspective, the magnetron sputtering titanium film process has no harmful gas or liquid emissions, which aligns with the sustainable development trend of the jewelry industry and holds great promise for application. This study has improved the visual effect and practical performance of the product, providing important theoretical basis and experimental data support for the application of environmentally

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friendly silver surface vacuum magnetron sputtering titanium thin film coating technology.

Keywords: Environmental Protection; Magnetron Sputtering; Silver; Colored Film; Titanium Film Layer

1. Introduction

Jewelry surfaces often need to be coated with metal film layers to enhance decorative and beautifying effects, prevent surface corrosion and discoloration, and improve surface wear resistance and scratch resistance [1]. Silver is an elegant white precious metal that has been loved by consumers since ancient times, with good conductivity, reflectivity, and corrosion resistance [2]. In previous studies, it has been found that the air contains ozone (O_3) with extremely strong oxidizing ability, as well as SO_2,H_2S, etc., and their trace presence is sufficient to cause silver to change color [3]. The surface color of silver gradually changes from the original silver white to yellow or dark, affecting its decorative effect. However, the current silver plating used in the jewelry industry mainly adopts electroplating technology, and most of them use toxic cyanide plating solution, which poses a great threat to people and the surrounding natural environment in production, transportation, storage or use. There are problems of high pollution, high energy consumption, and low efficiency, which limit production. Especially in the jewelry industry, there are still problems such as small production scale, scattered operation points, outdated technology, low industrial grade, and multiple safety hazards [4, 5]. With the continuous increase in environmental governance efforts, the scattered and extensive electroplating production mode in the jewelry industry is facing severe challenges, and there is an urgent need to seek green and environmentally friendly jewelry electroplating processes [6].

Magnetron sputtering coating is a process in which gas is ionized into ionic states and new electrons under vacuum conditions, and then bombarded with a target material under the action of an electric field. Neutral target atoms are sputtered onto the surface, and the film material is vaporized, evaporated, and deposited on the substrate surface through high-temperature heating to form a solid thin film. Compared with electroplated coatings, coatings prepared using PVD equipment have a thickness range of 1−10 μm and an accuracy controlled within 0.5 μm. The actual production efficiency of the magnetron sputtering process is higher than that of the electroplated silver process, and the coating is more uniform and environmentally friendly than electroplating [7]. Vacuum magnetron sputtering coating is a physical vapor deposition method, whose basic principle is to use positive ions generated by argon ionization to bombard the surface of the target material under certain vacuum conditions, so that the atoms of the bombarded material obtain sufficient energy, break free from the constraints of the raw material lattice, and sputter atoms or molecules, and then deposit them on the surface of the workpiece to form a film layer [8]. Compared with electroplating technology, magnetron sputtering coating has outstanding environmental advantages and is suitable for the deposition of various film materials, making it a highly promising new coating process in the jewelry industry [9–11]. However, the color performance of the colorful titanium film layer obtained by this process on silver substrates and whether it can meet the decorative requirements of silver jewelry products are also issues of concern in the jewelry industry.

Previous studies have shown that physical vapor deposition equipment is widely used in the textile, hardware, and machinery industries, such as plating decorative coatings of various colors and functions on watch straps, eyeglass frames, phone cases, and various hardware appliances, thereby enhancing the beauty and functionality of products [12]. Magnetron sputtering technology has been applied to materials with high hardness, such as aluminum alloys, copper, and stainless steel, with good results [13]. Yuan Junping also conducted experiments on 18K gold jewelry based on this technology and developed anti-fingerprint film technology [14]. At present, there is relatively little research on magnetron sputtering technology on silver metal. This article uses vacuum magnetron sputtering technology to deposit colored titanium thin film layers on silver substrates with silver contents of 92.5% (Ag925) and 99.9% (Ag999), quantitatively analyzes the color of the film layer, explores the influence of coating process and substrate surface state on the color of the film layer, and evaluates the color performance and anti discoloration performance of the film layer, in order to provide reference for environmentally friendly production practice of silver decoration magnetron sputtering titanium film layer.

2. Materials and Methods

2.1. Experimental Materials

2.1.1. Experimental Metal Materials

925 silver is commonly used as jewelry material in silver jewelry, and 925 silver is also the international standard silver for making silver jewelry. 925 silver refers to silver products with a silver content of 92.5%. Due to the high purity of silver, it is relatively soft. 925 silver contains 7.5% copper and other metals to give it ideal hardness. Therefore, this article studies 925 silver as the substrate for magnetron sputtering coating. At the same time, in order to compare the coating effect, two types of silver were selected, including pure silver flakes with a silver content of 99.9%.

2.1.2. Experimental Target Material

Using titanium as the target material, magnetron sputtering technology is carried out in the field of silver jewelry surface coating to achieve precious metal silver film coating technology. The characteristics of titanium are light weight, high strength, metallic luster, and good corrosion resistance. When titanium is placed in high-temperature air, it easily reacts with oxygen to produce titanium dioxide. By changing the thickness of titanium oxide covering the surface of the silver substrate, various bright colors can be produced [15]. Because silver metal is prone to oxidation and has lower hardness. In the experimental process, the titanium film layer was better coated on the silver metal and prevented oxidation, achieving the environmentally friendly application of magnetron sputtering technology in the field of silver jewelry surface decoration.

2.1.3. Experimental Gas

This experiment mainly uses high-purity argon gas and high-purity oxygen gas with a purity of 99.999% as experimental gases. In a high-temperature vacuum environment, the gas can react with the target material to form a colored film layer, enriching the surface of silver jewelry.

2.1.4. Experimental Equipment

This project uses VLead PVD-0970 physical vapor deposition (PVD) equipment, which includes a main unit, power cabinet, pump mechanical pump assembly, water machine, and oven components. The furnace diameter is 90 centimeters and there are two observation windows. The maximum vacuum degree is 5×10^{-4} Pa, the pumping speed is increased from atmospheric to 8.0×10^{-3} Pa, ≤15 min (cold state of the furnace), the pressure rise rate is ≦0.4 Pa h^{-1}, and it is fully controlled by PLC.

2.2. Experimental Methods

2.2.1. Sample Processing

Silver metal undergoes 8 steps including cutting, punching, enlarging holes, polishing, ultrasonic cleaning, degreasing, and drying. Firstly, cut and make several sheet-shaped specimens with dimensions of 10 × 20 × 1 mm. Use 1200 # sandpaper to polish the silver sheet until there are no obvious scratches on the surface, and then use 2000 # sandpaper to polish it until the first surface process is no longer visible and the color turns gray-white. Use 7000 # sandpaper to polish the sample to a polished state, and clean it several times with pure water. Next, add clean water and cleaning agent to the cleaning tank for ultrasonic cleaning of the silver sheet, ensuring that the water level is at 3/4 of the cleaning tank, and clean regularly for 8−10 minutes. After cleaning, perform chemical degreasing by hanging the silver sheet on a fine copper wire and soaking it in degreasing solution for 1−2 minutes. The degreasing fluid needs to be connected to a plating rectifier to convert the AC power supply into a stable DC power supply with a voltage set at 7.69 volts. Rinse thoroughly with plenty of water to remove the surface degreaser components, and rinse several times with pure water. Then use a hair dryer to blow dry the surface moisture at a vertical angle of 90° to dry the silver metal surface.

2.2.2. Vacuum Magnetron Sputtering Coating

Vacuum magnetron sputtering coating is a green and environmentally friendly coating treatment method with obvious effects, which has many advantages such as low deposition temperature, fast deposition speed, good uniformity of the deposited film, and composition close to the target material composition. The working principle of magnetron sputtering technology is that under high vacuum conditions, incident ions (Ar+) bombard the target material under the action of an electric field, and a strong magnet is installed below the target, with the N and S poles in the center and periphery, respectively. Electrons are bound around the target material by the Lorentz force and continuously move in a circular motion, generating more Ar+ions to bombard the target material, greatly improving sputtering efficiency. Sputtering controlled by strong magnets is called magnetron sputtering (**Figure 1**)[16].

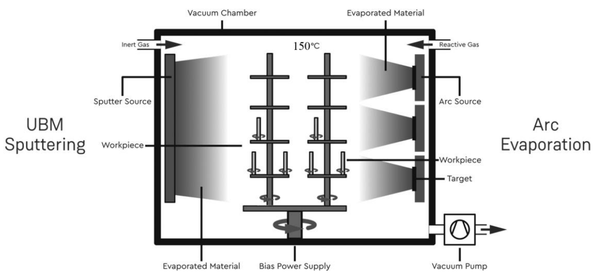

Figure 1. Schematic diagram of magnetron sputtering coating equipment.

By aligning the pre-treated silver sheet surface with the target surface and setting the plating time, the thickness and color of the metal surface coating can be controlled. Firstly, the vacuum extraction process is carried out by activating the pre-extraction pump and pre-extraction valve to evacuate the interior of the chamber to a pressure level below 4×10^{-2} Pa. Then, the Roots pump can be started and switched to the front stage valve. When the pressure inside the chamber further decreases to below 5 Pa, turn on the molecular pump. After the pressure inside the chamber is pumped to below 1 Pa and the molecular pump reaches the standby state, open the high vacuum valve and start heating the workpiece to the preset temperature. In order to enhance the adhesion between the workpiece surface and the deposited film layer, argon gas is introduced into the coating chamber while maintaining a vacuum degree of 1 Pa. Subsequently, the bombardment power supply is turned on to 880V. At this point, the bombardment electrode will trigger a glow discharge phenomenon, generating argon ions and high-energy argon atoms. Under the negative bias applied to the bombarding electrode, argon ions are accelerated and directed towards the bombarding electrode, thereby maintaining the continuous progress of glow discharge. At the same time, high-energy argon atoms undergo irregular thermal motion in the coating chamber, colliding with the workpiece due to their high-energy characteristics, transferring energy to the surface of the workpiece, and achieving the cleaning effect of the workpiece. After 5 minutes of glow cleaning, adjust the air pressure in the coating chamber to 0.4 Pa, and deposit a layer of titanium on the surface of the workpiece as the bottom layer through the target sputtering technology.

Under vacuum conditions, according to the specific experimental objectives, argon and oxygen are filled into the coating chamber, and the pressure inside the coating chamber is maintained at approximately 0.2 Pa. By heating at high temperatures, the film material is vaporized, evaporated, and deposited on the surface of the substrate to form a solid thin film. Under different process parameters, different colored film layers can be obtained. Given the high vacuum conditions inside the coating chamber, the average free path of gas molecules is significantly greater than the distance from the evaporation source to the workpiece. Therefore, after the atoms in the film layer evaporate from the evaporation source, they can avoid colliding with other gas molecules or metal vapor atoms, and instead directly shoot towards the surface of the workpiece to form the desired film layer. In a high vacuum environment, metal atoms fly directly towards the workpiece in atomic state, which helps to obtain a film layer with dense and fine structure, high hardness, high wear resistance (low friction coefficient), corrosion resistance, and chemical stability. The lifespan of the film layer is longer, and at the same time, the film layer can significantly improve the appearance and decorative performance of the workpiece.

2.2.3. Characterization Methods

To avoid subjectivity in observing the color of the film layer with the naked eye, the CM700d spectrophotometer and CIELab color index system are used to detect the color of the film layer. As a "standard eye", the spectrophotometer is widely used in color evaluation, color control, color blending, material composition analysis and other fields. Its Lab value is one of the three most commonly used coordinates for describing colors, including L, a, and b coordinates, representing brightness, red/green, and blue/yellow coordinates, respectively. The spectrophotometer is of great significance for detecting the quality of PVD coating color. Using a D65 light source, an observation angle of 10°, adopting SCI+SCE mode, taking 5 points on the cross diagonal to detect the reflectance and absorbance of the spectrum. Use the CIELab color index system for analysis, detect L* (brightness value), a* (red green degree value), and b* (yellow blue degree value), and take the average value[17]. Calculate the color difference ΔE of different samples according to Equation (1).

$$\Delta E=\sqrt{(L_1^*-L_0^*)^2+(a_1^*-a_0^*)^2+(b_1^*-b_0^*)^2} \quad (1)$$

Using LEXT OLS4500 laser confocal microscope to analyze 925 silver and 999 silver before coating, non-destructive observation was carried out on the samples without damaging or conducting conductive treatment. Methods including surface coating and morphology characteristics, measuring film thickness and three-dimensional contour, etc. can effectively evaluate the coating performance of silver alloys, determine their coating mechanism, and have important significance for the research and development of colorful silver alloy surface coatings.

The anti discoloration performance of the sample is tested by immersion corrosion test with artificial sweat. The specific preparation of artificial sweat includes the following components: urea concentration of 1 g L^{-1}, sodium chloride concentration of 5 g L^{-1}, and lactic acid content of 940 µL L^{-1}. The pH value of the solution is adjusted to 6.50, and the entire test process is carried out at a constant temperature of 30 degrees Celsius (°C). The polarization behavior of the membrane layer in artificial sweat was detected using a PARSTAT4000A electrochemical workstation and a three-electrode system. A saturated calomel electrode (SCE) was used as the reference electrode, pure platinum was used as the counter electrode, and the coated sample (exposed area 78.54 mm^2) was used as the working electrode. The scanning rate was 1 mV s^{-1}.

3. Results

3.1. The Influence of Coating Process on the Color of Film Layer

By setting different process parameters for the magnetron sputtering coating equipment, the color of the film layer, as shown in **Figure 2**, was obtained. Visually observing Ag925 and Ag999 under different process parameters, they exhibit changes in purple with a red tint, blue, yellow green, and yellowish purple.

In vacuum magnetron sputtering coating, different coating times and gas ratios are factors that affect the color of the film layer and can produce different colors[18]. In this experiment, the color change of the film layer during magnetron sputtering coating was studied by controlling the time and method of introducing different gases (argon and oxygen). The color of the film layer was detected using a CM700d spectrophotometer, and the color of the central area of the test piece was measured using a window with a diameter of 8 mm. Three measurements were taken at each position, and the average value was calculated (**Figure 3**).

Figure 2. Film color.

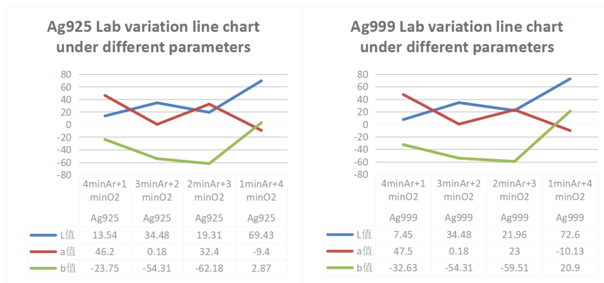

Figure 3. Line graph of lab variation of Ag925 and Ag999 under different parameter processes.

According to the color indicators in **Figure 3**, the color differences ΔE between the two with the same parameters were calculated to be 10.85, 0, 52.96, and 18.32, respectively. According to the correspondence between color difference and human perception given in **Table 1**, the color differences between Ag925 and Ag999 are respectively large, negligible, very large, and very large. This indicates that in the magnetron sputtering titanium plating process, there may be color unevenness in the film layer of samples with the same parameters, which has a significant visual impact on the film layer.

Table 1. Correspondence between color difference and visual perception [19].

ΔE	0–0.5	>0.5–1.5	>1.5–3.0	>3.0–6.0	>6.0–12.0	>12.0
Visual perception of color difference	Negligible	Slight	Perceptible	Recognizable	Large	Very large

3.2. The Influence of Substrate Surface State on Film Color

Process Ag925 and Ag999 into a sand pushing surface state, and apply magnetron sputtering coating for 5 minutes under the action of two different gases to study the effect of substrate surface state on film color. The three-dimensional contour of the silver substrate surface was observed using a laser confocal microscope, and the sand pushing surface was densely distributed with scratches in the same direction, with obvious ups and downs (**Figure 4**).

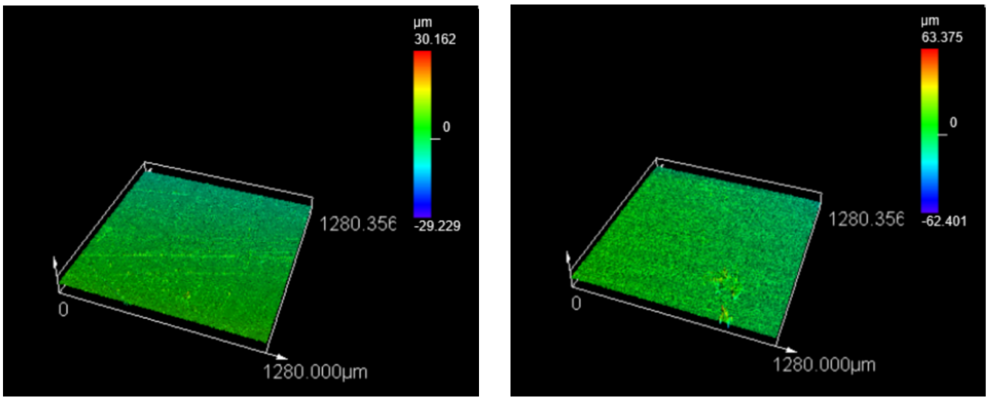

Figure 4. Three dimensional contours of Ag925 and Ag999 silver on the sand pushing surface.

3.3. Anti-Discoloration Performance Test

Select coated samples for artificial sweat immersion testing, measure the color of the samples at regular intervals, and calculate the changes in each indicator relative to the initial value [20]. The results are shown in **Figure 5**.

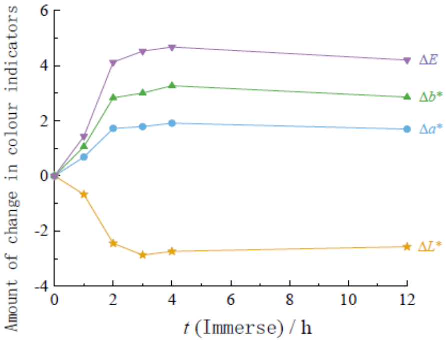

Figure 5. Color changes of silver titanium film layer in simulated artificial sweat immersion test.

4. Discussion

From the experimental results, it can be seen that the process parameter settings for vacuum magnetron sputtering titanium film coating, as well as the selection of silver with lower hardness as the substrate material, do indeed cause some problems, thereby affecting the results of magnetron sputtering coating. For example, with the same parameters and samples, the color of the film layer is uneven. There are three main reasons for this problem. Firstly, that Ag925 samples contain copper metal components, which can easily undergo chemical reactions under the action of temperature and gas, thereby affecting color. The second difference is the placement position of the sample, which can affect the color change of the coating when placed at different heights. As shown in **Figure 6**, the color of the suspension bracket at different positions inside the furnace after magnetron sputtering coating also varies greatly when observed by the naked eye. Thirdly, the lack of sample rotation resulted in uneven sputtering of the target material onto the surface of the silver material, which to some extent affected the bonding performance between the film layer and the material.

Figure 6. Color difference of the suspension bracket before and after magnetron sputtering in the furnace cavity.

But from an artistic design perspective, uneven and varied colors can have a unique effect on the design of silver jewelry, just like the popular titanium jewelry on the market, which attracts more and more consumers' attention by giving it surface color. In addition, Lab value testing is required on the silver surface after the experiment, so conventional anti-oxidation treatment was not performed on the surface of the coated silver jewelry, which is prone to oxidation after coating. As shown in **Figure 7**, the effects of oxidation and blackening before coating, just after coating, and three months later are shown.

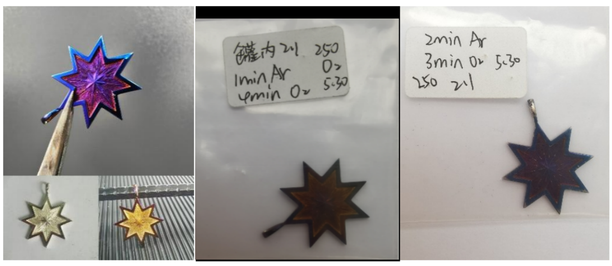

Figure 7. Comparison of pre coating, just after coating, and 3 months after coating.

4.1. The Influence of Different Gas Introduction and Time Differences on the Color of the Membrane Layer

The color change of the titanium film layer during magnetron sputtering was studied by controlling the time of oxygen, argon, and nitrogen gas injection within 5−10 minutes (**Table 2**).

1. The influence of oxygen, argon, and nitrogen. According to experimental observations, oxygen, argon, and nitrogen as reaction gases have a significant impact on the color of the coating layer. When argon gas is introduced, the film layer presents a darker metallic color or gray tone because argon gas does not participate in the chemical reaction of the film layer and maintains the original surface optical properties of the metal. When oxygen is introduced, the film layer exhibits a lighter metallic or blue color tone, due to the formation of oxides that alter the optical properties of the film surface. When only nitrogen gas is introduced, the membrane layer presents a lighter yellowish purple color tone.

2. The impact of time differences. In the experiment, it was also observed that as the gas was introduced for a longer period of time, the color of the film layer changed. The longer the oxygen is introduced, the lighter the color of the membrane gradually tends to be blue; as the time for introducing argon gas is prolonged, the color of the film layer tends towards a darker metallic color. This indicates that the gas passage time is one of the important factors in controlling the color of the film layer.

Table 2. The effect of time gas differences on film layer color.

Serial Number	Gas and Duration	Colour	Silver Sample Plate
1	5 min (4 min Ar + 1 min O_2)	Purple with a red tint	
2	5 min (3 min Ar + 2 min O_2)	Blue	
3	5 min (2 min Ar + 3 min O_2)	Blue	
4	5 min (1 min Ar + 4 min O_2)	Yellow green	

Table 2. *Cont.*

Serial Number	Gas and Duration	Colour	Silver Sample Plate
5	5 min N_2	Yellowish purple	
6	10 min (4 min Ar + 6 min O_2)	Purple with a red tint to blue purple	

4.2. Effects of Experimental Coating Layer Thickness

1. Multi-dimensional analysis of the influence of thickness on color characteristics. In the experiment of exploring magnetron sputtering coating technology in depth, the color changes of different thickness film layers were measured, aiming to reveal the inherent relationship between thickness and color characteristics. The experimental data clearly show that as the thickness of the film layer gradually increases, the depth of the metallic color exhibits a significant and orderly enhancement trend. This change is not only reflected in the depth of color, but also in the stability and glossiness of color. Specifically, thicker film layers can reflect light more effectively, making colors more vivid, long-lasting, and with better glossiness. This change mechanism is mainly attributed to the significant impact of the increase in film thickness on its optical reflection characteristics, thereby endowing the film with richer color expression and higher color saturation.

2. Comprehensive consideration and balance of thickness and functionality. In the application of magnetron sputtering coating technology, the thickness of the film layer is not only a key factor affecting color characteristics, but also an important parameter related to its practical application functionality. Especially in high-end applications such as jewelry, the thickness of the film layer not only determines the aesthetic appearance of the jewelry, but also directly affects its protective performance and service life. Therefore, when preparing magnetron sputtering coatings, it is necessary to comprehensively consider the dual effects of thickness on color and functionality. Within a certain range, increasing the thickness of the film layer can significantly improve its wear resistance and oxidation resistance, thereby extending the service life of jewelry. However, excessively thick film layers may also result in colors that are too dark or lose their natural luster, affecting the aesthetic effect. Therefore, in practical applications, it is necessary to carefully weigh the impact of thickness on color and functionality in order to achieve the best balance and meet the dual needs of beauty and practicality in high-end applications such as jewelry.

4.3. Anti-Discoloration Performance

As the experimental period increases, the brightness parameter L of the film layer shows an initial sharp decline trend, and then gradually tends to a stable state. At the same time, the chromaticity parameters a and b * show opposite trends of change, first rapidly increasing and then gradually stabilizing. The variation pattern of the color difference index $\Delta \boldsymbol{E}$ also conforms to this pattern, that is, it first increases rapidly and then remains stable. Especially after 12 hours of artificial sweat immersion testing, the color difference $\Delta \boldsymbol{E}$ reached 4.2, which is enough to be clearly recognized by the naked eye. However, compared to traditional electroplating film layers, the magnetron sputtering film layer used in this study exhibited superior anti-discoloration performance in artificial sweat environments.

5. Conclusions

This study systematically explored the effects of reaction gas type, exposure time, and film thickness on the color of titanium films deposited on 925 silver and 999 silver surfaces using vacuum magnetron sputtering technology. Additionally, the anti-tarnishing performance of the obtained films was evaluated. The following are the main research findings:

1. Relationship between reaction gas and film color

The experimental results show that oxygen, argon, and nitrogen, as reactive gases in the magnetron sputtering coating process, have a significant impact on the color of the film layer. Specifically, when oxygen is introduced into the coating chamber, the color of the film layer appears light blue or metallic, which may be due to the formation of oxides on the surface of the film layer caused by the introduction of oxygen, thus altering the optical properties of the film layer. Conversely, the introduction of argon causes the color of the film layer to shift towards a deep metallic color, as argon does not participate in chemical reactions during the coating process but maintains the original surface optical properties of the metal. Additionally, the introduction of nitrogen causes the color of the film layer to exhibit a light yellow hue. These results indicate that by adjusting the types and proportions of reactive gases, the color of magnetron sputtering coatings can be precisely controlled.

2. Impact of permeation time on the color of the membrane layer

The experiment also revealed that the duration of reactant gas introduction significantly influences the color of the film layer. With other conditions remaining unchanged, the color of the film layer gradually shifts towards a lighter blue as the oxygen introduction time increases, whereas an increase in argon introduction time leads to a deeper color of the film layer. This finding further underscores the importance of the duration of reactant gas introduction in controlling the color of the film layer. By precisely adjusting the gas introduction time, it is possible to achieve precise control over the color of the film layer, thereby obtaining the desired color effect.

3. Impact of film thickness on color and functional performance

This study also measured magnetron sputtering coating layers of different thicknesses and observed their color changes and functional properties. The results showed that as the thickness of the coating layer increases, the depth of the metallic color gradually increases, while the color stability and glossiness also improve. This is due to the increased optical reflection characteristics of the coating layer with increasing thickness, making the color more vivid and durable. Furthermore, within a certain thickness range, the coating layer can not only provide good color effects but also maintain its functionality in practical applications, such as wear resistance and oxidation resistance. These results indicate that controlling the thickness of the coating layer during the magnetron sputtering process is crucial for achieving ideal color effects and functional properties.

4. Anti-tarnishing performance test

To evaluate the anti-tarnishing performance of the obtained film layer, this study selected coated samples for artificial sweat immersion testing. The results indicated that the film layer exhibited good anti-tarnishing performance in the artificial simulated sweat immersion test. This finding further confirms the potential application value of magnetron sputtered titanium films in the field of silver jewelry surface decoration.

5. Summary of environmental performance

During the process of magnetron sputtering titanium gold coating, no harmful gases or liquids are produced, thus exerting minimal impact on the surrounding environment [21]. This reduces environmental pollution and the impact on workers' health, aligning with the sustainable development trend in the jewelry industry.

In summary, this study conducted a systematic experimental exploration and data analysis to delve into the application of magnetron sputtering titanium thin film technology on silver jewelry materials and its influencing factors. These research findings not only contribute to optimizing coating process parameters, enhancing the visual effects and practical performance of products, but also provide important theoretical basis and experimental data support for the application of environmentally friendly vacuum magnetron sputtering titanium thin film coating technology on silver surfaces [22].

Author Contributions

Methodology and review, K.D. and C.A.; verification, writing—Initial draft preparation, H.Z. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

You'll find all my research data in scopus and research.

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Conflicts of Interest

The authors declare no conflict of interest.

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