Journal of Materials, Processing and Design (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/jmpd.2024.080207
ISSN 2516-0923 Vol. 8 Num. 2

Study on the Microscopic Morphology and Tribological Properties of Composite Films Prepared by Magnetron Sputtering

ANNISAA PRASTIKA BAHDIE

Department of Mechanical Engineering, College of Engineering, Yangzhou University, Yangzhou, Jiangsu, 225127, China

Keywords: Cr2O3-TiO2-2 composite film; Magnetron sputtering; Micro-morphology; Tribological properties

Abstract: The purpose of this study is to discuss the micro-morphology and tribological properties of Cr2O3-TiO2 composite films. In this paper, Cr2O3-TiO2 composite films were prepared by magnetron sputtering technology, and the microstructure and tribological properties of the films were comprehensively characterized and tested by scanning electron microscope, atomic force microscope and friction and wear testing machine. The experimental results show that proper sputtering power can significantly improve the surface quality and wear resistance of the films. The films prepared at 200W sputtering power show the best microstructure and tribological properties. In addition, it is found that the composition of the thin film has an important influence on its properties, and the contents of Cr, Ti and O in the thin film can be optimized by adjusting sputtering parameters, thus improving its properties. The study reveals the relationship between the micro-morphology and tribological properties of Cr2O3-TiO2-2 composite films, and provides theoretical support for further optimizing the preparation process and improving its properties.

1. Introduction

With the rapid development of modern science and technology, thin film materials have attracted much attention because of their wide applications in micro-nano electronics, optics and machinery. Especially in improving the surface properties of materials, enhancing wear resistance and corrosion resistance, thin film technology shows great potential [1]. Cr2O3 and TiO2 _ 2 are both important inorganic materials, which have obvious advantages in their respective application fields [2]. Cr2O3 is famous for its high hardness, excellent chemical stability and good wear resistance, and is widely used in wear-resistant coatings, ceramic materials and other fields [3]. On the other hand, because of its excellent photocatalytic performance, high refractive index and good chemical stability, TiO2 has broad application prospects in photoelectric devices, self-cleaning materials and so on [4].

In the film preparation technology, magnetron sputtering technology is widely used because of its advantages of fast deposition rate, good film quality and high material utilization rate [5]. This technology bombards the target with high-energy particles, so that the atoms or molecules of the target are sputtered out and deposited on the substrate, thus forming a thin film [6]. By accurately controlling sputtering parameters, the structure and properties of thin films can be controlled on the nanometer scale. The purpose of this study is to prepare Cr_2O_3-TiO_2 composite films by magnetron sputtering technology, and to deeply discuss their micro-morphology and tribological properties. By studying the changes of microstructure and properties of thin films under different preparation conditions, it is expected to reveal the internal relationship between the composition, structure and properties of thin films, and provide theoretical basis for optimizing the preparation process and improving the properties of thin films.

In this paper, a series of experiments will be designed and implemented to prepare Cr_2O_3-TiO_2 composite films with different compositions and structures by changing sputtering parameters. Then, the surface morphology and structural characteristics of the films will be analyzed by using advanced micro-morphology observation techniques, such as scanning electron microscope (SEM) and X-ray Diffraction (XRD). At the same time, the tribological properties of the film were tested by friction and wear tester, including key indexes such as friction coefficient and wear rate. During the experiment, the experimental conditions are strictly controlled to ensure the reliability and accuracy of the data. Through in-depth analysis and comparison of experimental data, it is expected to reveal the internal relationship between the micro-morphology of the film and its tribological properties.

2. Experimental method

2.1. Experimental materials

The target materials used in the experiment are high-purity Cr_2O_3 and TiO_2. In order to ensure the quality of the film, strict screening and processing were carried out on the target material to ensure its purity and uniformity. The substrate material selected is monocrystalline silicon wafer, which is suitable as a substrate for thin film growth due to its smooth surface and stable chemical properties. Before sputtering, the substrate was thoroughly cleaned and dried to remove surface impurities.

2.2. Film preparation

The thin film is prepared using magnetron sputtering technology. During the sputtering process, use a high-power magnetron sputtering device. The device is equipped with a precise control system that can monitor and adjust sputtering parameters in real time. By adjusting key parameters such as sputtering power, sputtering time, and gas pressure, the composition, thickness, and microstructure of the thin film can be precisely controlled [7].

Prior to sputtering, multiple vacuuming and inflation operations were performed on the sputtering chamber to ensure optimal gas purity and pressure. During the sputtering process, an alternating sputtering method was adopted, which involves first sputtering a layer of Cr_2O_3, then sputtering a layer of TiO_2, and repeating this process until the predetermined film thickness is reached.

2.3. Microscopic morphology observation

In order to investigate the microstructure of thin films in depth, two advanced microscopic observation techniques, scanning electron microscopy (SEM) and XRD, were adopted. SEM can provide high-resolution images of the surface morphology of thin films, helping us understand information such as particle size, distribution, and surface roughness of the films [8]. XRD can provide more precise surface morphology and nanoscale structural information, which helps to further reveal the microstructure and growth mechanism of thin films.

2.4. Tribological performance testing

To evaluate the tribological properties of the thin film, a friction and wear testing machine was used for testing. This testing machine can simulate the friction and wear process under actual working conditions, providing accurate friction coefficient and wear rate data. During the testing process, appropriate friction pair materials and testing conditions were selected to ensure the representativeness and comparability of the test results.

Before testing, the thin film samples were preprocessed and calibrated to ensure they met the testing requirements. During the testing process, real-time changes in friction coefficient and wear amount are recorded and processed through professional data analysis software. Through these data, we can gain a deeper understanding of the tribological performance and its variation patterns of thin films under different working conditions.

3. Experimental results

3.1. Microscopic observation results of thin films

Detailed microscopic observations were conducted on the prepared $Cr2O3-TiO2$ composite thin films using scanning electron microscopy (SEM) and XRD. The observation results reveal key information such as surface morphology, particle size, and distribution of the thin film.

Table 1 shows the surface roughness data of thin films under different sputtering parameters. As the sputtering power increases, the surface roughness of the thin film shows a trend of first decreasing and then increasing. Due to the increase in sputtering power, the target atoms obtain higher energy, making it easier to form a uniform thin film on the substrate; But when the sputtering power is too high, it leads to an increase in the mobility of atoms on the substrate, which in turn increases the surface roughness.

Table 1: Surface roughness of thin films under different sputtering parameters

Sputtering power (W)	Sputtering time (min)	Surface roughness (nm)
100	30	12.5
150	30	8.2
200	30	5.6
250	30	7.3
300	30	9.8

3.2. Composition analysis of thin films

To determine the composition of the thin film, we conducted energy dispersive X-ray spectroscopy (EDS) analysis. Table 2 shows the content of Cr, Ti, and O elements in the thin film under different sputtering powers. As the sputtering power increases, the content of Cr element gradually increases, while the content of Ti element gradually decreases. Due to the increase in sputtering power, the sputtering efficiency of $Cr2O3$ target material is improved, resulting in an increase in the content of Cr element in the thin film.

Table 2: Element content of thin films under different sputtering power

Sputtering power (W)	Cr content (%)	Ti content (%)	O content (%)
100	28.5	35.2	36.3
150	32.7	31.8	35.5
200	37.2	28.1	34.7
250	41.5	24.6	33.9
300	45.3	21.2	33.5

3.3. Test results of frictional properties of thin films

Table 3 shows the friction coefficient and wear rate of the thin film under different sputtering parameters. As the sputtering power increases, the friction coefficient of the thin film first decreases and then increases, while the wear rate shows a gradually decreasing trend. Due to the denser microstructure of the thin film under appropriate sputtering power, its wear resistance is improved.

Table 3: Friction coefficient and wear rate of thin films under different sputtering parameters

Sputtering power (W)	Friction coefficient	Wear rate (10-6 mm3/Nm)
100	0.65	2.8
150	0.58	2.3
200	0.51	1.8
250	0.55	1.5
300	0.61	1.3

4. Discussion

This study investigated the microstructure and tribological properties of Cr2O3-TiO2 composite films. Thin films were prepared by magnetron sputtering technology, and comprehensive characterization and performance testing were conducted using various experimental methods.

From the microscopic observation results, the surface roughness of the thin film shows a trend of first decreasing and then increasing with the increase of sputtering power. At lower sputtering power, the energy obtained by the target atoms is limited, making it difficult to form a uniform and dense thin film on the substrate, resulting in higher surface roughness. With the increase of sputtering power, atoms obtain higher energy, enhance mobility, and facilitate the formation of a smoother thin film surface. However, when the sputtering power is too high, the energy of the atoms is too high, leading to excessive migration on the substrate, which actually destroys the uniformity of the film and increases surface roughness. Therefore, selecting the appropriate sputtering power is crucial for controlling the surface quality of the thin film.

From the composition analysis results, it can be seen that the content of Cr, Ti, and O elements in the film changes with the increase of sputtering power. This change not only affects the physical properties of the film, but also has a significant impact on its tribological properties. The increase of Cr element can improve the hardness and wear resistance of the film, but excessive Cr content can also lead to increased brittleness of the film. Therefore, when optimizing the performance of thin films, it is necessary to comprehensively consider the content and interaction of various elements.

In the tribological performance testing, it was found that the friction coefficient and wear rate of the thin film showed a certain variation pattern with the increase of sputtering power. Appropriate sputtering power can significantly improve the wear resistance of thin films. This is related to the denser microstructure and optimized element content of the thin film prepared at this power.

However, excessive sputtering power can lead to a decrease in film performance, which may be related to an increase in surface roughness and changes in element content.

It is worth noting that in addition to sputtering power, other preparation process parameters such as sputtering time, gas pressure, etc. may also have an impact on the performance of the thin film. Therefore, in subsequent research, the influence of these parameters on the properties of thin films can be further explored to seek the optimal preparation process conditions.

5. Conclusions

This study successfully prepared Cr_2O_3-TiO_2 composite thin films using magnetron sputtering technology, and systematically studied their microstructure and tribological properties using various advanced experimental methods. The experimental results indicate that sputtering power has a significant impact on the microstructure, composition, and tribological properties of the thin film.

Under appropriate sputtering power, the thin film exhibits a more uniform and dense microstructure with lower surface roughness, which lays the foundation for its excellent tribological performance. By adjusting the sputtering parameters, the element content in the thin film can be effectively controlled, further optimizing its performance. Experimental data shows that the thin film prepared at a specific sputtering power has a lower friction coefficient and wear rate, exhibiting good wear resistance.

By precisely controlling the preparation conditions, excellent performance Cr_2O_3-TiO_2 composite films can be obtained, which have potential application value in the field of tribology.

References

[1] Zhang Jian, Niu Yonghui, Wang Zhe. Influence of parameters on properties of Cr_2O_3-TiO_2 coating for blast furnace tuyere sprayed by supersonic plasma [J]. Hot working technology, 2019,48(04):184-187+198.

[2] Zhang Jian, Niu Yonghui. Microstructure and tribological properties of Cr_2O_3-TiO_2 coating sprayed by supersonic plasma [J]. Weapon Materials Science and Engineering, 2018,41(04):76-81.

[3] Back G S, Yoon M J, Jung W G. Effect of the Cr2O3 and TiO2 as nucleating agents in SiO2-Al2O3-CaO-MgO glass-ceramic system[J]. Metals and Materials International, 2017, 23(4):798-804.

[4] Kumar G S P, Keshavamurthy R, Akhil M P, et al. Friction and wear behaviour of HVOF sprayed Cr2O3-TiO2 coatings on aluminium alloy[J]. International Journal of Materials Engineering Innovation, 2021, 12(1): 1-17.

[5] Özel C, Zirek A. Microstructure and wear behavior of Cr2O3-40% TiO2 coating on magnesium alloy via plasma spraying [J]. Journal of Physical Chemistry and Functional Materials, 2020, 3(1): 28-35.

[6] Chen Chunjiang, Jia Bi, Wang Yunfei, et al. Microstructure and electrochemical properties of plasma sprayed Cr2O3/TiO2 high temperature oxide ceramic composite coating [J]. Surface Technology, 2019, 48(9):224-229.

[7] Jia Bi, Pan Fusheng, Chen Chunjiang, et al. Study on the influence of Al_2O_3 on the properties of plasma sprayed Cr_2O_3/TiO_2/Al_2O_3/SiO_2 composite ceramic coatings [J]. Surface Technology, 2020, 49(08):55-62.

[8] Zhu Yanyu, Wang Yici, Zhang Heng, Luo Guoping, Huo Xiaogeng. Effect of Cr2O3 and TiO 2 on crystallization mode of glass-ceramics prepared from blast furnace slag [J]. Silicate Bulletin, 2017, 36(11):3835-3840.