Design, Preparation and Service Behavior of MAX Phase Coatings

by Zhenyu Wang | Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences

Abstract ID: 10178
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: MAX phase; High-purity; Corrosion resistance; PVD technique;

The ternary layered Mn+1AXn (MAX phases) as a special category of materials with a closely-packed hexagonal structure, exhibit exceptional mechanical properties akin to metals and ceramics, along with superior high-temperature oxidation resistance, radiation tolerance, and corrosion resistance. These attributes make them one of the ideal protective coating materials for critical power systems in marine, energy, aerospace, and other sectors, garnering significant attention. However, the production of high-purity MAX phase coatings at low temperatures is challenging, the high ratio of metallic bonding leads to lower hardness, and the interfacial diffusion behavior and damage mechanisms during force-thermal-salt service are not well understood, which greatly limits their widespread application. To address these issues, the speaker and their team conducted extensive systematic research and proposed a novel method for the low-temperature preparation of high-purity dense MAX phase coatings via PVD composite solid-phase reactions. They established criteria for the low-temperature phase formation design of MAX phases; developed new solid-solution coating systems for MAX phases that feature low-temperature self-healing of defects and robust high-temperature self-lubrication; and elucidated the oxidation corrosion mechanism of Al-based MAX phase coatings in various environments (mid/high-temperature steam, mid-temperature salt spray, high-temperature air, etc.). The above work will provide theoretical guidance and technical support for applications in fields such as aviation engines and nuclear reactor cladding.

Effect of nitrogen flow on the structural and properties of TiVCrNiSi(N) high entropy nitride coating deposited by arc ion plating

by Menghui Cui | Xiaoyun Ding | Yawen Wu | Yong Lian | Jin Zhang | University of Science and Technology Beijing | University of Science and Technology Beijing | University of Science and Technology Beijing | University of Science and Technology Beijing | University of Science and Technology Beijing

Abstract ID: 10297
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: Arc ion plating, High-entropy nitride coating, Nitrogen flow, Wear

In order to solve the problems of low surface hardness and poor wear resistance of Ti6Al4V, arc ion plating was used to adjust different nitrogen flow (R_{N2}=0 %, 10 %, 20 %, 30 % and 40 %) to prepare (TiVCrNiSi)Nx nitride coating. The microstructure, mechanical properties and wear resistance of the coating were studied. The results show that the coating deposition rate is more than 110 nm/min with different nitrogen flow, and reaches 184 nm/min when R_{N2} is 40 %. As the nitrogen flow rate increases, the coating gradually changes from the BCC to the FCC phase, and the amorphous phase of metal silicide is detected in the coating. The adhesion strength of the coating first decreases and then increases with the addition of nitrogen. The optimal adhesion strength of the TiVCrNiSi coating is 54.6 N. The coating adhesion strength decreases to 21 N at R_{N2}=10%, and further increases the nitrogen flow to reach 41 N (R_{N2}=40%). As the nitrogen flow increases, the coating hardness tends to increase, reaching 17 GPa when R_{N2} is 40 %. The wear mechanisms of all coatings are mainly abrasive wear and adhesive wear. When R_{N2} is 40 %, the coating shows the lowest wear rate (1.19×10^{-4} $mm^3/(N\cdot m)$) which is only 17 % of the Ti6Al4V matrix. CrN in the coating is preferentially converted into high-hardness Cr_2O_3 during the wear process, effectively improving the wear resistance of the coating. In addition, the higher metal Ni in the coating ensures the plasticity of the coating. Therefore, the (TiVCrNiSi)N high-entropy nitride coating prepared by arc ion plating on titanium alloy surfaces can effectively solve the problems of low hardness and poor wear resistance of titanium alloy surfaces, and broadens the development path for titanium alloys in wear-resistant conditions.

Effect of vacuum atomic oxygen irradiation on the tribological properties of fullerene-like carbon films

by Kaixiong Gao | Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences

Abstract ID: 10559
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: atomic oxygen, friction, fullerene-like carbon films, space irradiation

The development of highly reliable, low-friction, durable lubrication materials and technologies applicable to the space environment will be of great importance to improve the lubrication status and life of space equipment. Fullerene-like films exhibit excellent ultra-low friction and wear resistance under atmosphere and vacuum, and are considered to be one of the most promising materials for space lubrication. In this work, the effect of vacuum atomic oxygen on the mechanism of action and tribological properties of fullerene-like carbon and MoS_2 films were investigated. After atomic oxygen irradiation, the content of odd-membered rings in the fullerene-like carbon films decreased, the sp^2 carbon converted to sp^3. Besides, the total proportion of carbon atoms in the form of oxides did not increase significantly (from 11.3% to 13.0% only), and the hydrogen content in the films did not change significantly due to the existence of the cage-like structure of the fullerene-like carbon films. After atomic oxygen irradiation, it was more difficult to form fullerene-like nanostructures at the interface of the friction surface during the friction process, resulting in the increase of friction coefficient. For the MoS_2 film, the hardness was drastically decreased after atomic oxygen irradiation, causing it to wear out quickly under high contact stress.

Hydrophobicity and friction properties of phosphonic acid self-assembled monolayers on the surface of 3D printed zirconia ceramic parts

by Yan Lou | shenzhen university

Abstract ID: 10327
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: Phosphonic acid self-assembled monolayers; 3D printed zirconia ceramics; Hydrophobicity properties; Frictional performance; Packing density

SAMs technology, as a controllable surface modification technique, has great potential in micro/nanostructure manufacturing. Ceramic materials are considered ideal for micro/nano mold materials due to their high wear resistance and high thermal stability. 3D printing technology, compared to traditional methods, has the ability to fabricate ceramics parts with complex structures and precise dimensions. However, the poor surface roughness and severe hydrophilicity of 3D printed ceramic parts hinder their application in micro/nano molds. Improving the surface properties of ceramic materials in 3D printed parts has been a key research focus in the field.

In this study, the focus was on investigating the effect of phosphonic acid self-assembled monolayers (SAMs) on improving the hydrophobicity properties of 3D printed zirconia ceramic surfaces. Among the three different SAMs, namely pure hexadecylphosphonic acid (HPA), pure dodecylphosphonic acid (DDPA), and a 1:1 mixture of hexadecylphosphonic acid-dodecylphosphonic acid (HPA-DDPA), it was found that the HPA-DDPA SAMs exhibited the highest water contact angle, indicating the best hydrophobicity. It was also found that the HPA-DDPA SAMs had the smallest surface roughness, with a decrease of 29.2% compared to the bare substrate.

Furthermore, the experimental results showed that the mechanism by which phosphonic acid SAMs reduce the friction coefficient of zirconia ceramic surfaces primarily involves lubrication, intermolecular interactions, and changes in surface hydrophobicity. Phosphonic acid SAMs reduce adhesion and friction by forming a smooth molecular layer, reducing direct contact, and decreasing van der Waals forces. The improved hydrophobicity, reduced adhesion, and decreased friction coefficient collectively alleviate adhesion wear and abrasive wear on the zirconia ceramic surface, resulting in reduced scratch width, wear width, and wear depth, and improved wear resistance. Additionally, the packing density of phosphonic acid SAMs also plays an important role in surface friction properties, with the HPA-DDPA SAMs having the highest packing density and exhibiting the best friction performance.

Influence of surface coating on the antenna performance at mmWave frequency band

by Ying-Chih Chiang | Yu-Hsun Chang | Cheng-Hsien Chou | Cheng-En Ho | Yuan Ze University, Taoyuan 320, Taiwan, R.O.C. | Yuan Ze University, Taoyuan 320, Taiwan, R.O.C. | Unitech Printed Circuit Board Corp., New Taipei City 236, Taiwan, R.O.C. | Yuan Ze University, Taoyuan 320, Taiwan, R.O.C.

Abstract ID: 10107
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: 76–81 GHz, HFSS, antenna, mmWave, surface coatings

Millimeter wave (mmWave) frequency band (specifically 76–81 GHz) has received widespread attention in the advanced driver-assistance systems (ADAS) as its high sensitivity, long range, and beam-steering radar characteristics. The adoption of surface coatings in a mmWave antenna device can protect its Cu circuits from oxidation and abrasion. However, additional surface coatings might significantly alter the electrical properties of Cu circuits due to the skin effect arising from mmWave transmission, thereby affecting the overall performance of mmWave antenna. The focus of this study is to probe into the effect of surface coatings (immersion tin, Au/Ni(P), Au/Pd(P)/Ni(P), Au/Pd(P)/Au, and immersion gold) on the antenna characteristics (return loss, gain, radiation pattern, and beamwidth) in the 76–81 GHz band via finite element analysis (FEA) method through using a 3D electromagnetic simulation software (ANSYS-HFSS). Additionally, vector network analyzer (VNA) measurements and anechoic chamber experiments were conducted to evaluate the antenna characteristics with different surface coatings, so as to validate the FEA simulation results. Details regarding the effect of surface coatings on the antenna performance will be presented in this talk.

Low secondary electron emission characteristics of carbon nano-onion coating via plasma enhanced chemical vapor deposition

by Jie Yang | Institute of Fluid Physics, China Academy of Engineering Physics

Abstract ID: 10121
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: Carbon nano-onion, Defects, Electron capturing trap., Secondary electron emission, Surface coating

Suppression of secondary electron emission (SEE) by surface coating technology on metal materials has important applications in many fields, for which the investigation on new coating materials with low secondary electron yield (SEY) is desired significantly. In this study, the maximum SEY of nickel (Ni) substrate was reduced from 2.30 to 0.75 (67% reduction) after a carbon nano-onion (CNO) coating prepared by plasma enhanced chemical vapor deposition (PECVD), and the SEY less than 1 means that some problems caused by secondary electron (SE) multiplication on metal materials could be solved completely. Various measurements, material characterization and CASINO Monte Carlo model simulation indicated that the low SEY characteristic of CNO coating could be attributed to two main mechanisms: Firstly, true SEs emitted from the surface of CNO could be reabsorbed by the adjacent CNO attributed to the micrometer scale undulating structure formed by the accumulation of CNO on the coating surface; Secondly, the defects degree of CNO directly affects the emission of true SES, which plays the role of low-energy electron capturing trap. This discovery can provide a reference for future coating production.

Mechanical properties and damage mechanism evolution of TiZrHfNb/TiAlN films subjected to cyclic nano-impact

by Qun Cai | Southeast university of China

Abstract ID: 10394
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: TiZrHfNb/TiAlN; HiPIMS; High strain rate cyclic impact; Damage mechanism

For the purpose of preventing the compressor blades from sand erosion , a novel TiZrHfNb/TiAlN multilayer coatings were prepared using high impulse power magnetron sputtering. The phase constituents and mechanical properties of TiZrHfNb/TiAlN coatings were investigated. Nano-impact test was used for evaluating the dynamic response and film failure mechanisms subjected to high strain-rate repeated load. Combined with the FEM model of the stress distribution, the strengthening-toughening mechanism of soft-hard alternating multilayer coating and the effect of the interface in impact damage were discussed. The results suggested that the TiZrHfNb/TiAlN coatings have dense microstructure, higher adhesion strength (26.7 ± 1.8 N), and lower residual stress (−1.85 ± 0.04 GPa) compared with monolithic TiAlN coating. During the repetitive impact process, high tensile stress is the main reason for the formation and propagation of brittle cracks in the coating. The introduction of the TiZrHfNb layer promoted the formation of the shear band and increased the toughness, consuming impact energy and reducing the maximum tensile stress. Therefore, it shows a higher impact resistance than the TiAlN monolayer coating. It is inferred that the fracture failure mechanism of the TiZrHfNb/TiAlN coating is a joint mechanism of brittleness and toughness.

Preliminary study of α-Ta multilayer alternating coating: through bias control

by Xiaoyun Ding | Menghui Cui | Yong Lian | Jin Zhang | Yawen Wu | University of Science and Technology Beijing | University of Science and Technology Beijing | University of Science and Technology Beijing | University of Science and Technology Beijing | University of Science and Technology Beijing

Abstract ID: 10296
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: α-Ta; AEGD; DCMS+HiPIMS; bias control; multilayer alternating coating

To achieve high properties of α-Ta alternating multilayer coatings, this work used arc-enhanced glow discharge (AEGD) and high-power impulse magnetron sputtering (HiPIMS) techniques. By integrating direct-current magnetron sputtering (DCMS) with HiPIMS, single-layer and multilayer coatings were successfully produced at a deposition rate exceeding 6 μm/h. The microstructure, mechanical properties, electrochemical behavior, and thermal shock resistance of the coatings were investigated in this work. By controlling the deposition bias, the crystal structure, fracture toughness, and adhesion strength of the multilayer alternating coating remained essentially unaltered. Simultaneously, specific properties could be modulated within a defined range, including: hardness (600-775 HV0.05), electrical resistivity (15-25 μΩ·cm), and self-corrosion current density (1.40×10^{-8}-9.00×10^{-9} A·cm^{-2}). Notably, coatings fabricated under optimized alternating bias exhibited exceptional stability, covering all substrate surfaces even after exposure to 50 thermal shock cycles from 700 to 25 °C.

Preparation and anticorrosion performance of composite silane films incorporating graphene oxide additives modified with 2,6-diaminopyridineon sintered NdFeB

by Zhu Tao | Li Jiang | Siyu Chen | Shuting Xu | Yanxia Liang | Yumeng Yang | Benfeng Zhu | guoyingwei@cjlu.edu.cn | Yu Chen | College of Materials and Chemistry, China Jiliang University, Hangzhou, Zhejiang 310018, P. R. China | College of Materials and Chemistry, China Jiliang University, Hangzhou, Zhejiang 310018, P. R. China | College of Materials and Chemistry, China Jiliang University, Hangzhou, Zhejiang 310018, P. R. China | College of Materials and Chemistry, China Jiliang University, Hangzhou, Zhejiang 310018, P. R. China | College of Materials and Chemistry, China Jiliang University, Hangzhou, Zhejiang 310018, P. R. China | College of Materials and Chemistry, China Jiliang University, Hangzhou, Zhejiang 310018, P. R. China | College of Materials and Chemistry, China Jiliang University, Hangzhou, Zhejiang 310018, P. R. China | School of Materials Science and Hydrogen Energy, Foshan University, Foshan, Guangdong 528000, P. R. China

Abstract ID: 10383
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: Corrosion resistance, Modified graphene oxide, Silane film, Simulation, Sintered NdFeB

In this work, 2,6-diaminopyridine modified graphene oxide (DMGO) was designed as the additive, which was co-deposited with silane on sintered NdFeB magnets to prepared hydrophobic and anti-corrosive DMGO/silane composite films via an electrochemically assisted sol-gel method. Structural and compositional analysis were conducted by Fourier transform infrared spectroscopy, Raman spectra, X-ray photoelectron spectroscopy and scanning electron microscopy, which results confirmed the successful grafting of 2,6-diaminopyridine on GO. The silane coupling agents linked to the DMGO additives, as well as the sintered NdFeB magnets surface through covalent bonds. Simulations were carried out to investigate the influence of DMGO concentration and deposition potential on the corrosion resistance of the prepared composite films. Consequently, the optimal deposition condition was proposed. Corrosion resistance properties of the prepared composite films in 3.5 wt.% NaCl solution were studied by electrochemical impedance spectroscopy and potentiodynamic polarization. The corrosion current density (j_{corr}) of DMGO/silane film under the optimal deposition condition was found to be 2.922×10^{-7} A/cm^2, which value was one order of magnitude lower than that of the neat silane film. The improved anticorrosive property of DMGO/silane composite film can be primarily attributed to the grafted 2,6-diaminopyridine, which significantly enhanced the barrier effect of GO by improving its dispersion within the sol-gel system. Meanwhile, the co-deposited DMGO remarkably reinforced the three-dimensional network structure of the composite film. Moreover, the corrosion protection performance of the composite films on sintered NdFeB was predicted using simulation software.

Research progress in the design, preparation, and application of advanced functional coating materials by plasma enhanced physical vapor deposition

by Yanfeng Wang | Shaopeng Wang | Juanjuan Geng | Northwest Institute for Non-ferrous Metal Research | Northwest Institute for Non-ferrous Metal Research | Northwest Institute for Non-ferrous Metal Research

Abstract ID: 10524
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: coating, corrosion, interface strengthen, structural degsin, toughness

Advanced functional coatings, possessing special physical and chemical properties, could enhance the surface service performance of materials in harsh environments. By adopting the plasma assisted vapor deposition technology, Multi-element-doped super hard and self-lubricating coating materials, hard yet tough nanometer multilayer composite coating materials and durable corrosion-resistant functional coating materials were explored. Correspondingly, the strengthening theory of these coating materials was studied. A microstructure with multiphase structure composite could be formed by mutual doping of alloying elements, and the dispersion distribution of amorphous C phase was obtained, which significantly improved the micro hardness of the coating while also having good self-lubricating function; By designing the modulation ratio and modulation period between the hard metal nitride layer and the soft metal layer, the fracture toughness of hard coatings can be improved without reducing the surface hardness; Through the rational design of coating elements and the strengthening effect of high-energy particles on the coating and also the interface between substrate and coating, a coating with higher interface bonding strength was synthesized, and also the structural density and integration of the coating were improved. Then the high durable corrosion resistance of coating was enhanced due to the optimization of the structure. More importantly, much more researches on the application of advanced functional coating materials for engineering applications were carried out, including the Design of structure, Elements filtering, and Development of batch process, obtaining advanced coating materials suitable for engineering application.

Revealing failure mechanism of Ti/TiN/TiAlN multilayer coatings erosion resistance and micropillar compression

by Jingjun Yan | Zhenyu Wang | Aiying Wang | Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences | Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences | Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences

Abstract ID: 10164
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: TiAlN multilayer coatings, erosion resistance, fracture toughness, micro-nano mechanics, uniaxial compression

The service life of turbine engine blades used in offshore and desert is frequently compromised by erosion caused by solid particles. Surface protective coating offer a promising protocol to significantly enhance the erosion resistance of compressor blades. In this study, we employed a home-made hybrid multisource cathode arc system to deposit the Ti/TiN/TiAlN multilayer coatings onto Ti-6Al-4V substrates, and TiN-Ti-TiN stress absorption layers were periodically incorporated within the TiAlN layer. The underlying microscale mechanisms responsible for coating failure due to erosion and micro-pillar compression have been thoroughly elucidated. The results indicated that the presence of metal/ceramic interfaces significantly improved adhesion, crack resistance, erosion resistance, and fracture toughness of the coatings. Plastic flow of the soft layer metal primarily influenced the deformation behavior of the multilayer coatings. Notably, during the yielding process, the Ti layer effectively reduced elastic strain energy by generating nanotwins, coherent interfaces, and high-density dislocations, thus enhancing the deformation characteristics of the coatings. Furthermore, the introduction of stress-absorbing layers effectively hindered radial crack propagation, resulting in a transition from brittle fracture to a coordinated brittle-ductile fracture mechanism. The findings highlight the significance of metal/ceramic interfaces and stress absorption layers in improving erosion resistance and fracture behavior of TiAlN-based hard coatings.

Sandwich-zigzag structure enhanced erosion resistance of TiN coatings

by Li Wang | Key Laboratory of Marine Materials and Related Technologies, Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences

Abstract ID: 10053
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: Erosion protection; Boundary orientation; Sandwich-zigzag; energy dissipation; Cracks deflection.

Titanium nitride (TiN) hard coatings have been widely studied as candidates for erosion protection of engine blades. However, the traditional monolayer and multilayer TiN coatings are still apt to be worn due to their high brittleness or low fracture toughness under sand particle impaction. Here, taking the concept of grain boundary orientation design, we fabricated the sandwich-zigzag multilayered TiN coatings by tilting magnetron sputtering technique. Results showed that the sandwich-zigzag structure significantly improved the erosion resistance of the normal TiN coatings, which could be attributed to the enhanced energy dissipation at the crack tip and the deflected propagation of cracks in the coatings.

Strengthening of Ti2AlC MAX phase coatings induced by solid solution of zirconium on the M-site

by Kaihang Wang | Aiying Wang | Ningbo Institute of Materials Technology & Engineering, Chinese Academy of Sciences | Ningbo Institute of Materials Technology & Engineering, Chinese Academy of Sciences

Abstract ID: 10118
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: High-purity (Ti, MAX phase, Mechanical properties, Solid solution strengthening, Ti2AlC coating, Zr)2AlC

Ti_2AlC MAX phase exhibits exceptional resistance to oxidation and corrosion, making it an ideal candidate for protective coating in harsh environments, while the subpar mechanical properties limit its potential for broader applications. Herein, high-purity $(Ti, Zr)_2AlC$ coatings were successfully synthesized on Ti-6Al-4V alloy substrates using high power impulse magnetron sputtering technique with subsequent annealing at 750 ℃. X-ray diffraction (XRD) analysis confirmed the substitution of Ti with Zr on the M-site within the Ti_2AlC lattice, resulting in the formation of $(Ti_{0.9}Zr_{0.1})_2AlC$ solid solution phase. The incorporation of Zr into Ti_2AlC coatings decreased surface roughness and grain size, attributable to the impediment of nucleation and atomic diffusion. Consequently, the hardness and resistance to plastic deformation of $(Ti_{0.9}Zr_{0.1})_2AlC$ coatings were enhanced in comparison to the Ti_2AlC coating, as a result of the combined effects of solid solution strengthening and grain refining strengthening mechanisms. However, this enhancement comes with a trade-off, as a slight reduction in toughness was observed in the $(Ti_{0.9}Zr_{0.1})_2AlC$ coating.

Study of magnetron sputtered Cr/FeCrAl multilayer coatings on Zr substrates for accident tolerant fuel claddings

by Xiaoling Yang | Chongqing University

Abstract ID: 10105
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: Magnetron sputtering; Cr/FeCrAl coating; Zr alloy; High-temperature steam oxidation; Microstructure

Accident tolerant fuel (ATF) claddings have been propounded to enhance the fuel performance both in normal operating and loss of coolant accident (LOCA) conditions. As a more near-term option, depositing protective coatings on Zr alloys could be considered due to its low manufacturing cost and good fuel compatibility. Among various coatings, FeCrAl coating is one of the candidate materials due to its good mechanical properties and oxidation resistance. However, severe Fe-Zr interdiffusion would adversely affect the properties of the FeCrAl-Zr cladding system, which limits its application at elevated temperatures. Thus, in this work, metallic Cr coating was introduced as the diffusion barrier layer because of its good high-temperature oxidation resistance and favorable adhesion with Zr. Furthermore, it was reported that multilayer coatings could enhance properties such as hardness and corrosion resistance. Therefore, the $(Cr /FeCrAl)_2$ coatings were also prepared to identify the effects of multilayer structure on the performance of Cr /FeCrAl coatings.

In this work, firstly, the effect of substrate bias on microstructure and mechanical properties of FeCrAl coatings on Zr alloys by magnetron sputtering were systematically investigated. Then the optimal deposition parameters, which provides dense structure and good adhesion, were used for the deposition of the Cr /FeCrAl and $(Cr /FeCrAl)_2$ coatings. Additionally, the high-temperature steam oxidation resistance at 1200℃ of three coatings (FeCrAl, Cr /FeCrAl, $(Cr /FeCrAl)_2$) were compared with SEM/EDS, XRD, EBSD, TEM, nanoindentation and adhesion tests.

The results show that the microstructure of FeCrAl coatings evolves from an apparent columnar structure to a highly dense one with the increase of bias. Additionally, the oxidation resistance and mechanical properties of $(Cr /FeCrAl)_2$ coatings are significantly better than that of FeCrAl and Cr /FeCrAl coatings for the reason that the increase of the number of interface layers could reduce the accumulation of defects and elemental interdiffusion.

Study on microstructure and friction mechanism of Mo incorporated (AlCrTiZr)N high - entropy ceramics coatings prepared by magnetron sputtering

by Deen Sun | Southwest University

Abstract ID: 10294
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: High entropy ceramics coatings, Mechanical properties, Tribological behavior

The $(AlCrTiZrMo_x)N$ coatings with varying Mo content were successfully prepared using a multi - target co - deposition magnetron sputtering system. The results reveal that the Mo content significantly affects the microstructure, hardness, fracture toughness, and tribological behavior of the coatings. As the Mo content in the coatings increases gradually, the preferred orientation changes from (200) to (111). The coatings consistently exhibit a distinct columnar structure. Additionally, the hardness of the coatings increases from 23.65 to 26.36 GPa, along with an increase in fracture toughness. The friction coefficient is reduced from 0.72 to 0.26, and the wear rate is reduced by 10 times. During the friction process, the inter-column regions of the coatings are initially damaged, causing the wear track to exhibit a wavy pattern. Greater frictional heat is generated at the crest of the wave, resulting in the formation of MoO_2 lubricating layer. The friction reaction helps to reduce the shear force during friction, demonstrating the lower friction coefficient of the $(AlCrTiZrMo_x)N$ coatings. Both the hardness and fracture toughness work together to reduce the wear rate, and the $(AlCrTiZrMo_x)N$ coatings show the excellent wear resistance. Most notably, although the columnar structure plays a negative role on the hardness, it contributes greatly to the wear resistance.

Superlubricity or not of carbon films for carbon natural

by Bin Zhang | Lanzou Institute of Chemical Physics, Chinese Academy of Science

Abstract ID: 10009
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: cabon film, super lubricity

Carbon films are kinds of high hardness, high anti-corrosion, high anti-wear and low friction protecting coatings. Some of carbon films are with superlowfriction attracted much attention due to the coefficient is in the scope of 0.001 or lower, much lower than that of 0.5-0.01 of real used lubricants. How to realize the industrial use the supelurbicious materials is a challenge. Here, we report our progress on carbon films with different work enviroment.

The effect of different energy laser shock peening on the performance of Cr coating on zirconium alloy surface

by Chuang-ming Ning | Shi-jia Yu | Guo-can Tang | Quan-yao Ren | Zhen-bing Cai | Key Lab of Advanced Technologies of Materials, Tribology Research Institute, Southwest Jiao tong University, Chengdu 610031, China | Tribology Research Institute, Key Lab of Advanced Technologies of Materials, Southwest Jiaotong University, Chengdu, 610031, China | School of Mechanical Engineering, Chengdu University of Technology, Chengdu 610031, China | Science and Technology on Reactor System Design Technology Laboratory, Nuclear Power Institute of China, 610213, Chengdu, China | Tribology Research Institute, Key Lab of Advanced Technologies of Materials, Southwest Jiaotong University, Chengdu, 610031, China

Abstract ID: 10456
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: Cr coating, Electrochemical corrosion, Laser shock peening (LSP), Zirconium alloy

The laser shock peening (LSP) technology is an advanced surface modification technology. It is also one of the commonly used methods for composite strengthening. The Cr coating was widely used for surface protection of Zirconium (Zr) alloy in pressurized water reactors (PWRS). In this study the Cr coating on the Zr alloy was treated with different energy laser shock peening. And the corrosion resistant and surface integrity of Cr coating on the surface of Zr alloy was investigated. The surface microstructure, phase composition, hardness, residual stress, and grain structure was characterized by scanning electron microscopy (SEM), X-ray diffraction (XRD), nanoindentation, residual stress meter and electron backscattered diffraction (EBSD). The corrosion resistance of Cr coated-Zr alloy with different laser energy treatment was also analyzed by the electrochemical workstation in the boron lithium aqueous solution. The results show that the cracks were introduced on the surface of Cr coating after different energy LSP treatment. The hardness is increased with the laser energy increase. Compared with the Cr coating without treatment, the grain structure has undergone significant changes. The corrosion resistance was improved after LSP treatment. The influence of different energy laser shock strengthening on the performance of Cr coatings was discussed.

The growth of (HfNbTaTiZr)Ox high-entropy oxide thin films by pulsed laser deposition

by Muhamad Jalu Purnomo | Yu-Chieh Lee | Ching-An Huang | Ing-Song Yu | National Dong Hwa University, Hualien, Taiwan | National Dong Hwa University, Hualien, Taiwan | Chang Gung University, Tao-Yuan, Taiwan | National Dong Hwa University, Hualien, Taiwan

Abstract ID: 10057
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: (HfNbTATiZr)Ox thin film, X-ray photoelectron spectroscopy, nanoindentation, pulsed laser deposition, spectroscopy ellipsometry

In recent year, high-entropy oxides (HEOs) thin films have attracted considerable attention owing to their superior physical, chemical, and optical properties. Concurrently, pulsed laser deposition (PLD) has gained prominence as a technique for thin film fabrication. This study focuses on synthesizing high-entropy oxides, particularly $(HfNbTaTiZr)O_x$, which were meticulously prepared on silicon (111) substrate in a high vacuum chamber maintained at room temperature. This preparation involved variable deposition times (1, 2, and 3 hours) and differing pulse energies (400, 500, and 600 mJ). To thoroughly evaluate these films, a comprehensive array of analytical methods was employed, providing a detailed examination of the films' morphological characteristics, chemical composition, mechanical properties (including elastic modulus and nano-hardness), and optical properties.

The morphological analysis, encompassing both macroscopic and microscopic assessments, disclosed a variety of colors and surface features, such as bubble formation and a significant increase in surface roughness after the annealing process. X-ray photoelectron spectroscopy (XPS) was instrumental in offering a detailed analysis of the films' chemical state, confirming their oxide composition. Notably, nanoindentation tests revealed that the $(HfNbTaTiZr)O_x$ films possessed superior nano-hardness and elastic modulus. The study observed an initial enhancement in both elastic modulus and nano-hardness with an increase in deposition time and pulse energy, reaching an optimal performance at 2 hours of deposition and 600 mJ of pulse energy, before experiencing a slight decline.

Furthermore, after annealing, spectroscopic ellipsometry indicated a reduction in the films' optical properties. These extensive findings not only demonstrate an advanced approach to the fabrication of HEOs but also significantly advance our understanding of their mechanical and optical behaviors, offering meaningful insights with substantial implications for future technological developments.

Three-dimensional ZnO:Al multicomponent thin films prepared using a novel dual-mode atomic layer deposition method

by Hsuan-Fu Wang | Ching-Chiun Wang | Shih-Chin Lin | Chun-Hui Wang | Chih-Hung Liu | Meng-Chi Huang | Da-Jeng Yao | Industrial Technology Research Institute, Mechanical and Mechatronics System Research Labs | Industrial Technology Research Institute, Mechanical and Mechatronics System Research Labs | Industrial Technology Research Institute, Mechanical and Mechatronics System Research Labs | Asahi-Utou Technology Co., Ltd. | Industrial Technology Research Institute, Mechanical and Mechatronics System Research Labs | Industrial Technology Research Institute, Mechanical and Mechatronics System Research Labs | Industrial Technology Research Institute, Mechanical and Mechatronics System Research Labs

Abstract ID: 10425
: ThinFilms2024
Symposium: 5. Coating towards Industrial Applications (CIA)
Keywords: dual mode ALD, high aspect ratio, multi-component films

The manufacturing of novel three-dimensional structural coatings is increasingly focused on multicomponent films and pore-filling encapsulation. To meet the demand for high-capacity high-density electronic devices, conformal coatings of advanced ZnO:Al nanofilms with high aspect–ratio multilayers are urgently needed. Depositing films thicker than 100 nm through traditional physical vapor deposition is challenging, particularly fabricating films with a high aspect ratio (10:1), multicomponent accuracy, and coating uniformity. A novel dual-mode atomic layer deposition method can address the aforementioned shortcomings of traditional methods and produce highly conformal layers for all thin-film deposition techniques. This article introduces a low-temperature (<100 °C) atomic layer deposition device patented by the Mechanical & Mechatronics Systems Research Laboratories of the Industrial Technology Research Institute, Taiwan. The multicomponent precursor process of the dual-modal equipment was optimized to achieve even conformal deposition. Multicomponent coatings with nonuniformity of <3.6% were obtained using a discrete feeding method, which improved the plating rate and the ability of the coating material to infiltrate the pores within the substrate material. These improvements meet industrial specifications for producing highly uniform multicomponent thin films.