Size-dependent radiation tolerance and corrosion resistance in ion irradiated
CrN/AlTiN nanofilms

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Abstract

This paper demonstrates a substantial enhancement in radiation tolerance and corrosion resistance for the CrN/AlTiN multilayered nanofilms with the decreasing of period-thickness. After irradiation by 190 keV Ar⁺ ions to the dose of 81 dpa, the amorphization region in the CrN/AlTiN 3 nm multilayered nanofilm is much smaller than that in the CrN/AlTiN 7 nm multilayered nanofilm and the CrN film based on glancing-incidence X-ray diffraction measurements. Potentiodynamic polarization and impedance measurements show that the CrN/AlTiN multilayered nanofilms have good corrosion resistance to irradiation. With increasing the irradiation fluence, the irradiated samples are more susceptible to corrosive electrolyte. However, the CrN/AlTiN multilayered nanofilm with smaller period-thickness shows significant enhancement of the corrosion resistance under both irradiation and un-irradiation conditions. Under the same irradiation fluence of 5×10¹⁶ ions/cm², the corrosion current density increased 9.47 times for the CrN film, while it only increased 2.08 times for the CrN/AlTiN 3 nm multilayered nanofilm. The interfaces of multilayered nanofilms act as effective sinks for irradiation-induced defects and are responsible for the enhanced radiation tolerance and corrosion resistance properties.

Key words: radiation tolerance; corrosion resistance; multilayered nanofilm.

1. Introduction

Utilization the next generation of nuclear energy technology as a viable source of power is focused on the requirement of significant materials research and development. In nuclear reactors, materials are exposed to harsh environments including high-fluence neutron bombardment, high temperature and strong corrosive environment, all of which pose a significant challenge for the nuclear material scientists. In nuclear reactor plants, neutron transmutation, α decay can produce a large number of defects, such as interstitials, vacancies and clusters. The accumulation of defects can lead to swelling, hardening, amorphization, embrittlement and creeping of materials. These behaviors will change their intrinsic physical, mechanical and thermal properties and cause materials degradation and failure. Thus, development of novel materials with the abilities of radiation tolerance and corrosion resistance is of great significance. In order to create radiation and corrosion resistant materials that can withstand the extreme operating conditions, a fundamental understanding of the influences of radiation-induced defects on the corrosion behavior of materials is important to improve the reliability, lifetime and efficiency of materials in nuclear energy systems.

The model systems containing dense nanocrystal or multilayered film nanocomposites with grain boundaries/interfaces have been well known to be radiation resistant because grain boundaries and interfaces serve as efficient defect sinks to reduce damage accumulation and possible swelling. Nanoscale metallic multilayers such as Cu/W, V/Ag, Cu/Nb show extreme tolerance to He bubble swelling and good microstructural stability due to an enhancement of He solubility at interfaces [1-3]. Bulk nanocrystals can also exhibit extraordinary radiation healing

behavior due to accommodation and annihilation of defects by grain boundaries [4,5]. Nanostructured ferritic Fe-Cr-based steels containing ultrahigh densities of nano-precipitates (Y-Ti-O) were performed to tolerate the radiation-induced defects [6,7]. Our previous study showed that the multilayered CrN/AlTiN nanofilm with the period-thickness of 3 nm also had better radiation tolerance upon ion irradiation than the ones with larger period-thickness [8]. As a unique group of ceramics, metal nitride multilayered nanofilms have shown improvement in the properties like hardness, thermal stability, and tritium diffusion resistance as compared to their single layered films. It is important to note that to be a qualified material of the multilayered nanofilm served for nuclear reactors, it should withstand the strong chemical interactions coming from coolants accompanying radiation. Although, it has been reported that multilayered nanofilms show better corrosion resistance than the single layered films [9] and it is found that radiation damage affects the corrosion process [10-12]. There is very limited information about the influence of radiation damage on the corrosion behaviors of the multilayered nanofilms exposed to various working fluids in nuclear reactors. Studies on the corrosion behaviors of the irradiated single layered and the multilayered nanofilms are of great significance.

In the present work, we concentrate on the evaluation of the electrochemical behavior of the irradiated multilayered CrN/AlTiN nanofilms deposited on mirror-polished stainless steel substrates, with a special emphasis on the influence of period-thickness and the radiation fluence on the corrosion resistance of these multilayered nanofilms before and after irradiation. We found that the multilayered nanofilm with the smaller period-thickness has not only the best radiation tolerance, but also the best resistance to corrosion under both irradiation and un-irradiation conditions.

2. Experimental details

The multilayered CrN/AlTiN nanofilms with the period-thicknesses of 3 and 7 nm, were deposited on mirror-polished stainless steel substrates, respectively, which have been described in our previous work [8]. For comparison, the CrN film was deposited as well. The total film thicknesses of CrN film and CrN/AlTiN 7, 3 nm nanofilms were kept at about 2 μm . The CrN film and the CrN/AlTiN multilayered nanofilms with period-thicknesses of 7 and 3 nm were irradiated by 190 keV Ar^+ at room temperature to fluences of 1×10^{16} , 3×10^{16} and 5×10^{16} ions/ cm^2 , respectively. Glancing-incidence X-ray diffraction (GIXRD) studies were performed with a PANalytical X'pert MPD Pro diffractometer operated at 40 kV and 40 mA using Ni-filtered Cu K α irradiation (wavelength 1.5406 Å). The glancing incident angle was fixed at $\omega = 1^\circ$. Electrochemical measurements were carried out in a electrochemical station (Shanghai Chenhua CHI660D) using a conventional three-electrode cell, which had a platinum counter electrode of 1 cm^2 area and a saturated calomel electrode (SCE) as the reference electrode. The sample to be tested was the working electrode and was placed in Teflon sample holder and the exposed surface area to the corrosive medium was approximately 0.25 cm^2 . The corrosion measurements were carried out in 3.5% NaCl solution at room temperature, non-stirred and free air conditions. The sample was placed in such a way that the Luggin capillary of the reference electrode was close to the working electrode and this distance was maintained for all the tests. The sample was immersed in the solution for about 60 min prior to the potentiodynamic polarization study in order to establish the open circuit potential (E_{ocp}) or the steady state potential.

Impedance measurements were performed using a frequency response analyzer. The electrochemical impedance spectroscopy (EIS) was measured at the open circuit

potential and was recorded in the frequency range 10 mHz-100 kHz with data density of 5 points per decade. Impedance data was exhibited by Nyquist plots, which are a plot of real (Z') versus imaginary impedance (Z''). After EIS measurements, the system was allowed to attain open circuit potential. The polarization curves were obtained with a scan rate of 1 mV/s and the upper and the lower potential limits of linear sweep voltammetry were set at ± 200 mV with respect to the E_{ocp} . The Tafel plot was obtained after electrochemical measurements. The corrosion potential and the corrosion current density were deduced from the linear analysis of Tafel approximation.

SRIM 2008 was used to simulate the damage profile in the CrN film and the CrN/AlTiN multilayered films caused by Ar^+ ion irradiation. The peak displacements per atom (dpa) are 85 and 81 at the depth of 70 nm and 84 nm from the film surfaces for CrN and CrN/AlTiN, respectively, with the threshold displacement energies of 25, 25, 25 eV for Cr, Al, Ti, N, respectively. It is worthwhile to note that SRIM has limitations in predicting interfacial damages in a multilayered structure. Thus, SRIM simulation used here is primarily as a guide to estimate the peak damage location in the multilayered structure.

3. Results and discussion

Figure 1 depicts the glancing-incidence X-ray diffraction spectra of the CrN film and CrN/AlTiN multilayered nanofilms with period-thicknesses of 7 and 3 nm before and after 190 keV Ar^+ ion irradiation to the fluence of 5×10^{16} ions/cm². All the samples have a polycrystalline microstructure with the peaks of (111), (200), (220), (311), which are indicative of FCC structure. As shown in Fig. 1a, an obvious decrease (88%) in diffraction intensity of CrN (111) peak is observed from the

1 irradiated CrN as compared to that of the un-irradiated CrN film. After irradiation, the
2 CrN/AlTiN multilayered nanofilms still retain the polycrystalline FCC structure. As
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4 shown in Fig. 1b and 1c, a decrease of the peak (111) intensity from CrN/AlTiN 7 and
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6 3 nm multilayered nanofilms are 61%, 23%, respectively. The reduced peak intensity
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8 indicates the disordering in the crystal lattices of the samples due to radiation-induced
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10 defects. The results in Fig. 1 reveal that different degrees of damage including
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12 amorphization were formed in the CrN film, CrN/AlTiN 7 and 3 nm multilayered
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14 nanofilms to the fluence of 5×10^{16} ions/cm². At room temperature, the defects have
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16 low migration rates, and they can not recombine (or annihilate) or be absorbed by the
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18 interfaces rapidly, which may be responsible for the disordering behavior [13]. At a
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20 higher irradiation temperature, disordering behaviors in the CrN/AlTiN multilayered
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22 nanofilms may be different, but they requires further studies. Jiang, et al. have
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24 confirmed that amorphization of nanocrystalline SiC appeared under ion irradiation at
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26 room temperature and grain growth at 550 K [13,14]. The amorphization region in the
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28 irradiated CrN is resulted from the accumulation of primary displacement defects,
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30 such as interstitials, vacancies or their clusters and a possible nitrogen loss by ion
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32 bombardment [15]. Comparing to the irradiated CrN sample, the CrN/AlTiN
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34 multilayered nanofilms show an obvious suppression of damage, which indicates that
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36 the interfaces between CrN and AlTiN effectively assist defect annihilation. The
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38 interface effect in the CrN/AlTiN multilayered nanofilms is the period-thickness
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40 dependent, where the CrN/AlTiN 3 nm nanofilm shows the least amorphization with
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42 the decrease of 23% in the diffraction intensity of peak (111) from the XRD
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44 measurement. It is contributed to that the interstitials and vacancies generated during
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46 ion irradiation diffuse to nearby interface region and recombine or annihilate more
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48 effectively at the interfaces. Similar enhanced radiation tolerance properties were
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1 reported in the case of multilayered TiN/AlN and TiN/MgO nanofilms under He ion
2 irradiation [15,16]. Therefore, the XRD study confirms that the radiation-induced
3 damage in the CrN film and the CrN/AlTiN multilayered nanofilm is period-thickness
4 dependent, which is consistent with the TEM and HRTEM results in our previous
5 study. Otherwise, from the point of thermodynamic [17], for two-phase multilayered
6 nanofilms, a set of empirical rules have been proposed to explain the amorphization
7 under irradiation with different material parameters [18,19]. One of these rules is the
8 requirement for a negative heat of compound formation [20], which means that
9 irradiated two-phase multilayered films with large negative heats of formation tend to
10 amorphization while those with positive heats of mixing remain crystalline. This view
11 has been further supported by the fact that no amorphization appeared in irradiated
12 multilayered Cu/Nb films irrespective of the period-thicknesses of 4 nm or 40 nm,
13 where the heat of mixing between Cu and Nb is $\sim +10$ kJ/mol [21]. In our experiments,
14 the multilayered CrN/AlTiN 3 nm nanofilm has the best amorphization resistance,
15 which partly may be due to the positive heats of mixing [22].

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17 The potentiodynamic polarization measurement was the technique adopted to
18 evaluate the effect of the damage on the electrochemical behavior. Figure 2 presents
19 the potentiodynamic polarization curves of the CrN film and the multilayered
20 CrN/AlTiN with the period-thicknesses of 7 and 3 nm nanofilms deposited on
21 stainless steel before and after irradiation in 3.5% NaCl solution, which consist of the
22 cathodic and anodic potentiodynamic polarization curves. The corrosion current
23 density (i_{corr}) values and the corrosion potential (E_{corr}) were obtained from the
24 intersection of the cathodic and anodic Tafel curves extrapolated from the cathodic
25 and anodic potentiodynamic polarization curves. The corresponding corrosion
26 parameters such as corrosion potential, corrosion current density and polarization

resistance calculated from Tafel extrapolation are listed in Table 1. The corrosion potential does not provide much insight into corrosion rate [23]. However, it is well known that the corrosion current density is an important parameter to evaluate the kinetics of corrosion reactions. Corrosion rate is normally proportional to the corrosion current density measured via polarization [24]. The lower the i_{corr} , the lower corrosion rate the sample is. While, the higher the polarization resistance (R_p), the lower corrosion rate the sample is, the higher corrosion resistance is. The corrosion current density of the CrN film is $0.567 \mu\text{A}/\text{cm}^2$, which is higher than that of the multilayered CrN/AlTiN nanofilms. The corrosion current density of the CrN/AlTiN 7 nm multilayered nanofilm is $0.377 \mu\text{A}/\text{cm}^2$, which decreases to $0.127 \mu\text{A}/\text{cm}^2$ for the CrN/AlTiN 3 nm multilayered nanofilm. It indicates that the CrN/AlTiN multilayered nanofilms have better corrosion resistance than the CrN film and the CrN/AlTiN 3 nm multilayered nanofilm exhibits the best corrosion resistance property. Polarization resistance also increases in the same tendency. Similar phenomenon was reported in previous studies of the electrochemical measurements of transition metal nitride films [9]. As reported by others, the pore is one main factor affecting the corrosion resistance [25,26]. In polycrystalline CrN film, columnar structure with pores between the inter-granular columns formed during the deposition create a direct path for the corrosive electrolyte to pass through the defects. While in the process of depositing the multilayered CrN/AlTiN nanofilms, because CrN and AlTiN were deposited alternatively, the growth of the columnar structure of the individual CrN and AlTiN layer was restrained markedly. Associated with successive deposition of the sublayers, re-nucleation lowers the grain size and prevents the growth of pores and defects all through the films. A reduced grain size and a large number of interfaces between CrN and AlTiN result in dense and homogeneous microstructure. These factors can prevent

the electrolyte from penetrating through the films. Furthermore, due to the stress relaxation at the interfaces, multilayered films have lower residual stresses, thus inhibiting the crack propagation as a result of chemical attack. The presence of a large number of interfaces between individual layers of the multilayered structure also results in a drastic inhibition on pitting propagation [27], which contributes to the modification of localized corrosion mechanism. It can be concluded that with an increase of the number of interfaces in the films the corrosion resistance increases.

The corrosion current densities of the CrN film and the multilayered CrN/AlTiN with the period-thicknesses of 7 and 3 nm nanofilms before and after irradiation with different ion fluences were shown in Fig. 3. The corrosion current density of the irradiated CrN/AlTiN 7 nm multilayered nanofilm by 1×10^{16} Ar⁺ ions/cm² is 0.587 $\mu\text{A}/\text{cm}^2$, which is some higher as compared to the corresponding un-irradiated sample. The corrosion current density (0.131 $\mu\text{A}/\text{cm}^2$) of the irradiated CrN/AlTiN 3 nm multilayered nanofilm by 1×10^{16} Ar⁺ ions/cm² nearly has no variation as compared to the corresponding un-irradiated sample, indicating that the CrN/AlTiN 3 nm multilayered nanofilms has better corrosion resistance. When the ion fluence was increased to 3×10^{16} ions/cm², the corrosion current densities of the irradiated CrN/AlTiN 7 and 3 nm nanofilms are 0.973, 0.300 $\mu\text{A}/\text{cm}^2$, respectively. Continually increasing the Ar fluence to 5×10^{16} ions/cm², the corrosion current density of the irradiated CrN/AlTiN 3 nm nanofilm slightly increase to 0.392 $\mu\text{A}/\text{cm}^2$. While the corrosion current densities of the irradiated CrN/AlTiN 7 nm nanofilm and the CrN film sharply increase to 4.787, 5.938 $\mu\text{A}/\text{cm}^2$, respectively. From Fig. 3, it can be clearly seen that the increase of corrosion current densities with increasing the ion fluences in CrN/AlTiN 3 nm is the slowest, which indicates that CrN/AlTiN 3 nm has the best corrosion resistance after irradiation. Otherwise, the corrosion current density

of the irradiated CrN with the fluence of 5×10^{16} ions/cm² has increased to 9.47 times as compared to the un-irradiated CrN. While, the corrosion current density of the irradiated CrN/AlTiN 3 nm with the fluence of 5×10^{16} ions/cm² has only increased 2.08 times as compared to the un-irradiated CrN/AlTiN 3 nm. It demonstrates that the multilayered CrN/AlTiN nanofilm with smaller period-thickness significantly enhances the corrosion resistance under the irradiation condition. During the irradiation, ion beam bombardment brings many sorts of defects, such as point defects (interstitials, vacancies) and dislocation loops. Considering the corrosion behavior, the radiation-induced defects act as active corrosion points and increase the surface heterogeneity. Otherwise, the radiation-induced defects can increase the electronic conductivity. The more defects are formed, the better conductivity of the CrN/AlTiN multilayered nanofilm, and hence, the worse electrochemical corrosion resistance. Furthermore, the interfaces near the surface regions in the irradiated CrN/AlTiN 3 nm to a fluence of 5×10^{16} ions/cm² and CrN/AlTiN 7 nm to a fluence of 3×10^{16} ions/cm² began to partially disappear, respectively, as displayed in TEM images in our previous work [8]. The disappearance of the interfaces possibly promotes the effect of pitting propagation. All these facts accelerate corrosion rate. A large number of works have proved that the interfaces in these multilayered nanofilms acted as effective sinks to store radiation-induced damages and external species to increase radiation tolerance. In the case of the CrN/AlTiN nanofilm with the smallest period-thickness, the radiation-induced defects have the smallest diffusion distance as compared to that in the nanofilm with larger period-thickness and defects can be more easily and quickly diffuse to the interfaces, where they recombined or annihilated. This can contribute to the much smaller irradiation damage in the irradiated CrN/AlTiN 3 nm multilayered nanofilm, where the intact interfaces between CrN and AlTiN still existed with the

fluence of 1×10^{16} ions/cm² as exhibited by the TEM image in our previous work [8].
With increasing the fluence or the period-thickness, more defects were produced and the interfaces were destroyed more severely, which directly result in an increase of electronic conductivity and decrease the corrosion resistance. It is worthwhile to note that although the damage region induced by ion irradiation is only up to about 200 nm underneath the surface, as simulated by SRIM and observed in TEM images in our previous work [8], the damage region has a dominant influence on the corrosion resistance of the multilayered nanofilms. It can be deduced that the much smaller variation of the corrosion resistance of the irradiated CrN/AlTiN 3 nm nanofilm compared to the irradiated CrN/AlTiN 7 nm nanofilm is mainly due to the better irradiation tolerance instead of the pristine more interfaces between CrN and AlTiN layers beyond the irradiation depth.

EIS technique is quite sensitive to changes in the resistive-capacitive nature of electrochemical interface, thus more effective for studying the localized corrosion via small pores. As a small amplitude sinusoidal signal is added to the EIS measurements, this technique does not appear to significantly accelerate the corrosion reaction, and therefore can be considered as a non-destructive method. Figure 4 show the Nyquist plots of the CrN film and the CrN/AlTiN 7, 3 nm multilayered nanofilms before and after irradiation, respectively. The Nyquist plots show a single semicircle for all the samples. At the lower frequencies the interception with the real axis is ascribed to the charge transfer resistance (R_{ct}) and at the higher frequencies the interception of real axis in the Nyquist plot is ascribed to the solution resistance (R_s). The R_{ct} value is a measure of electron transfer across the surface and is inversely proportional to corrosion rate. The single semi-circle behavior obtained for all these films is believed to be due to the short exposure time (1 h), which is not sufficient to reveal the

degradation of the substrate and it mainly reveals the corrosion reaction of the films. Before irradiation, the R_{ct} increases in the following order: CrN, CrN/AlTiN 7 nm, CrN/AlTiN 3 nm, which shows that the CrN/AlTiN 3 nm has higher corrosion resistance. After irradiation, as displayed in Fig. 4b-4d, the R_{ct} decreases with the increase of the ion fluences. When the sample is immersed in the electrolyte the defects in the film provide the direct diffusion path for the corrosive media. In this process the galvanic corrosion cells are formed and the localized corrosion dominates the corrosion process. The samples exhibited high charge transfer resistance, indicating a low corrosion rate. No significant variations were observed in the R_{ct} values for CrN/AlTiN 3 nm **layers irradiated** from 1×10^{16} ions/cm² to 3×10^{16} ions/cm² as compared to the irradiated CrN/AlTiN 7 nm. This shows that the structure of the CrN/AlTiN 3 nm irradiated to a lower fluence was slightly affected and indicates that the CrN/AlTiN 3 nm has good corrosion resistance even after irradiation because that it has good resistance to irradiation-induced damage.

After the potentiodynamic polarization measurements, the surface topographies of the CrN film and CrN/AlTiN multilayered nanofilms were also studied by SEM. Figures 5a1-5a2 show the surface topographies of the un-irradiated and irradiated CrN film to the fluence of 5×10^{16} ions/cm², respectively. Corrosion pits and corrosion products were observed in the un-irradiated and irradiated CrN film after corrosion. The diameter of the corrosion pit was smaller for the un-irradiated CrN film than that for the irradiated CrN film. The corrosion pits could be attributed to the flaking of the samples as a result of chemical attack. The corrosion underneath the film caused rust formation and consequently increased the interface volume, which resulted in delamination of the film. Figures 5b1-5b4, 5c1-5c4 show the planar SEM images of the un-irradiated and irradiated CrN/AlTiN 7, 3 nm multilayered

nanofilms with fluences of 1×10^{16} , 3×10^{16} , 5×10^{16} ions/cm², respectively. It can be observed that nearly no corrosion pits were formed after corrosion in the un-irradiated and irradiated CrN/AlTiN 7 nm with the fluence of 1×10^{16} ions/cm². With increasing the ion fluence to 3×10^{16} ions/cm², corrosion pits began to appear. Continually increasing the ion fluence to 5×10^{16} ions/cm², the diameter of the corrosion pit increased. However, in CrN/AlTiN 3 nm, the surface morphology had no obvious variation before and after irradiation, even to the highest fluence of 5×10^{16} ions/cm², no corrosion pits could be observed. In corroboration with the results of electrochemical characterization, a good corrosion resistance of the samples is evident from the absence of the corrosion pits. In the case of the multilayers, most of the micro-pores are blocked as a result of successive deposition of the two materials and the period-thickness is smaller, the number of interfaces is larger, which are responsible for higher corrosion resistance of the CrN/AlTiN multilayered nanofilms even exposed to radiation damage. The SEM results give the direct evidence that CrN/AlTiN 3 nm has the best corrosion resistance even the dose up to 81 dpa, which is consistent with the electrochemical measurement.

4. Conclusions

The systematic GIXRD and electrochemical measurements reveal that the CrN/AlTiN multilayered nanofilms exhibit better irradiation tolerance and corrosion resistance than the CrN film. The corrosion resistant properties of the irradiated multilayered nanofilms were even better than that of the un-irradiated CrN film. With the increasing ion fluence, the corrosion resistance of CrN, CrN/AlTiN 7, 3 nm becomes weaker. The corrosion current density, polarization resistance and charge transfer resistance of the irradiated CrN/AlTiN 3 nm have much smaller variation as

1 compared to that of the irradiated CrN, CrN/AlTiN 7 nm. The multilayered
2 CrN/AlTiN nanofilm with smaller period-thickness significantly enhances the
3 corrosion resistance both under irradiation and un-irradiation conditions. Much less
4 irradiation-induced damage and slightly destroyed interfaces in the irradiated
5 CrN/AlTiN 3 nm nanofilm contribute to higher corrosion resistance. The large
6 number of interfaces between CrN and AlTiN result in dense and homogeneous
7 microstructure, which can prevent the electrolyte from penetrating through the films.
8 The radiation-induced defects act as active corrosion points and increase the
9 electronic conductivity. The more defects are formed, the better conductivity of the
10 CrN/AlTiN multilayered nanofilm, and hence, the worse electrochemical corrosion
11 resistance. Our investigations demonstrate that interfaces in the CrN/AlTiN
12 multilayered nanofilms are effective sink positions for absorbing irradiation-induced
13 defects. Therefore, the interface effect could be a dominant factor in enhancing the
14 corrosion resistance. Our research proves that metal nitride multilayer nanofilms are
15 potential irradiation tolerant materials for the application in nuclear reactors.
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Figure captions

Fig. 1. GIXRD spectra of the CrN film (a) and CrN/AlTiN 7 (b), 3 (c) nm multilayered nanofilms before and after 190 keV Ar⁺ ion irradiation at ion fluence of 5×10^{16} ions/cm².

Fig. 2. Potentiodynamic polarization curves of the CrN film (a) and CrN/AlTiN 7 (b), 3 (c) nm multilayered nanofilms before and after irradiation with the fluence from 1×10^{16} ions/cm² to 5×10^{16} ions/cm², respectively.

Fig. 3. Corrosion current density vs. ion irradiation fluence for the CrN film and the CrN/AlTiN 7, 3 nm multilayered nanofilms.

Fig. 4. Nyquist plots of the CrN film, and CrN/AlTiN 7, 3 nm multilayered nanofilms before irradiation (a) and the irradiated CrN (b) film with the fluence of 5×10^{16} ions/cm², the irradiated CrN/AlTiN 7 (c), 3(d) nm multilayered nanofilms with the fluence from 1×10^{16} ions/cm² to 5×10^{16} ions/cm², respectively.

Fig. 5. Planar SEM images of the samples after corrosion testing: CrN (a1) and irradiated CrN with the fluence of 5×10^{16} ions/cm² (a2); CrN/AlTiN 7 nm (b1) and irradiated CrN/AlTiN 7 nm with the fluence of 1×10^{16} (b2), 3×10^{16} (b3), 5×10^{16} (b4) ions/cm²; CrN/AlTiN 3 nm (c1) and irradiated CrN/AlTiN 3 nm with the fluence of 1×10^{16} (c2), 3×10^{16} (c3), 5×10^{16} (c4) ions/cm².

Tables

Table 1. Potentiodynamic polarization data of the CrN film and CrN/AlTiN 7, 3 nm multilayered nanofilms before and after irradiation with the fluence from 1×10^{16} to 5×10^{16} ions/cm².

Samples	i_{corr} ($\mu\text{A}/\text{cm}^2$)	E_{corr} (V)	R_p ($\text{k}\Omega \text{ cm}^2$)
CrN	0.567	-0.276	84.892
CrN/AlTiN 7 nm	0.377	-0.233	131.782
CrN/AlTiN 3 nm	0.127	-0.248	224.349
CrN/AlTiN 7 nm 1×10^{16} ions/cm ²	0.587	-0.313	76.514
CrN/AlTiN 3 nm 1×10^{16} ions/cm ²	0.131	-0.225	201.349
CrN/AlTiN 7 nm 3×10^{16} ions/cm ²	0.973	-0.323	43.803
CrN/AlTiN 3 nm 3×10^{16} ions/cm ²	0.300	-0.275	181.520
CrN 5×10^{16} ions/cm ²	5.938	-0.487	8.346
CrN/AlTiN 7 nm 5×10^{16} ions/cm ²	4.787	-0.406	13.416
CrN/AlTiN 3 nm 5×10^{16} ions/cm ²	0.392	-0.330	100.052

Figures

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

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