Corrosion characterization of durable silver coatings by electrochemical impedance spectroscopy and accelerated environmental testing

Chung-Tse Chu, Peter D. Fuqua, and James D. Barrie

Highly reflective front-surface silver mirrors are needed for many optical applications. While various protective dielectric coating schemes have been developed, the long-term durability of Ag mirrors is still of great concern in the optics community for a variety of applications under harsh environments. The corrosion protection behavior of a SiN$_x$-coated silver-mirror coating scheme was tested with electrochemical impedance spectroscopy (EIS) and accelerated environmental testing, including humidity and salt fog tests. The EIS data obtained were fitted with different equivalent circuit models. The results suggested that the 100Å thick SiN$_x$ coating produced by rf magnetron sputtering was porous and acted as a leaky capacitor on the Ag film, whereas the addition of a NiCrN$_x$ interlayer as thin as 3Å between SiN$_x$ and Ag films resulted in a much denser SiN$_x$ coating with a low-frequency impedance value of 2 orders of magnitude higher than that without the interlayer. Humidity and salt fog testing of different silver coatings showed similar results. The 100Å SiN$_x$/3Å–NiCrN$_x$/Ag coating exhibited excellent corrosion resistance against the corrosive environments used in this study. © 2006 Optical Society of America

1. Introduction
Front-surface metal mirrors are commonly used as broadband reflectors in many optical applications such as astronomical telescopes, space sensors, displays, and high-power laser systems. Evaporated aluminum is the most widely used metal reflector for front-surface mirrors because it has high reflectance from UV to IR, adheres well to glass and other substrates, and does not tarnish in normal air owing to the formation of a self-protective native oxide layer. However, silver possesses the highest reflectivity from 400 nm through the IR and the lowest polarization splitting among all metals. As a result, silver also has the lowest emissivity of all metals in the visible and IR regions. For example, the emissivity of Ag is less than half that of Al in IR wavelengths. Low emissivity is very important for high-sensitivity optical measurements. Front-surface silver mirrors would be the first choice for many high-performance applications if its poor chemical and mechanical durabilities could be overcome. Bare silver is easily tarnished by the attack of common atmospheric pollutants such as salt fog, ozone, acids, chloride, and sulfur compounds. While various protective dielectric coating schemes have been developed, the long-term durability of Ag mirrors is still of great concern in the optics community for a variety of applications under harsh environments.

Wolfe et al. developed a durable Ag-mirror coating scheme; its optical and environmental performance have also been demonstrated recently. The mirror design consisted of a thin interlayer of nichrome nitride between the substrate and the silver film and another interlayer between the silver film and a 100Å layer of silicon nitride (Fig. 1). The interlayer between the SiN$_x$ and the Ag could average 10Å or less. Wolfe reported that the thin NiCrN$_x$ interlayer had a noncontinuous, islandlike structure and was essential to providing good chemical durability. It is intriguing that such a thin and discrete layer plays a key role in protecting the Ag coating. In an earlier study the mechanism by which the coating provides durability was investigated with both electrochemical impedance spectroscopy (EIS) and an acid-vapor exposure test. The EIS technique has been applied extensively in the study of corrosion protection of coatings on metals. It is useful in the
rapid assessment of the corrosion-resistant quality of coatings and the performance of lifetime predictions. The corrosion reaction of a metal in an aqueous electrolytic solution may be modeled by equivalent circuits. The fitting of EIS data to circuit models often facilitates an understanding of overall corrosion behavior and leads to more accurate predictions of corrosion rates. In this paper we present further results of EIS analyses on the durable silver mirrors and their correlation with conventional humidity and salt fog testing.

2. Electrochemical Impedance Spectroscopy

The electrochemical impedance technique involves the application of a small perturbation of potential on the order of 10 mV to an electrochemical system in the form of sine waves over a frequency range of several decades. The impedance \( Z \) of the electrochemical system is determined from Ohm’s law from the applied potential \( E \) and its measured current response \( I \):

\[
Z = E/I. \tag{1}
\]

The complex impedance at each frequency is usually expressed by its real component \( Z_r \) and its imaginary component \( Z_i \) in a Nyquist plot or by the impedance magnitude \( |Z| \) and a phase angle \( \alpha \) in a Bode plot (Fig. 2).

When a metal is exposed to an aqueous electrolyte, a simple corrosion process would be the combination of a corrosion reaction and an electrical double layer at the metal–electrolyte interface [Fig. 3(a)]. This simple process can usually be described with a Randles circuit, shown in Fig. 3(b). The Randles equivalent circuit is one of the simplest and most common circuit models of electrochemical impedance. It includes a solution resistance \( R_s \), a double-layer capacitance \( C_{dl} \), and a charge transfer or polarization resistance \( R_{ct} \). In addition to being a useful model in its own right, the Randles cell model is often the starting point for other more complex models. From circuit analysis, the impedance of the Randles circuit is calculated as

\[
Z(\omega) = R_s + \frac{R_{ct}}{1 + \omega^2 R_{ct}^2 C_{dl}^2} + \frac{j\omega R_{ct}^2 C_{dl}}{1 + \omega^2 R_{ct}^2 C_{dl}^2}, \tag{2}
\]

where \( j = \sqrt{-1} \) and \( \omega \) is the angular frequency. The Nyquist and Bode plots in Fig. 2 give an example of the impedance spectrum of this simple corrosion process. The values of \( R_s \) and \( R_{ct} \) can be readily obtained from the plots, whereas that of the double-layer capacitance is evaluated from the Nyquist plot according to

\[
\omega_{\text{max}} Z_i = \frac{2\pi f_{\text{max}} Z_i}{C_{dl} R_{ct}}, \tag{3}
\]

where \( \omega_{\text{max}} Z_i \) and \( f_{\text{max}} Z_i \) are the angular frequency and frequency, respectively, at top of the semicircle in the Nyquist plot.

When a metal is protected with a dense dielectric coating with minimal defects, the electrochemical interface generally has high impedance. The coating acts like the dielectric in a capacitor such that the simple RC circuit shown in Fig. 4(a) can be employed to describe this situation, where \( R_s \) is the electrolyte resistance and \( C_f \) is the capacitance of the dielectric coating. As most protective coatings have pinholes and other permeable defects, the more complex model shown in Fig. 4(b) is often used to study the localized corrosion of coated metals. In such cases the electrolyte solution would penetrate the coating at defect sites and corrosion reactions would occur at the interface between the metal substrate and the coating. The \( (R_p, C_f) \) pair is used to describe the charge transfer and the electrical double layer of electrolyte at the interface; \( R_p \) and \( C_f \) represent the pore resistance to
the ionic current through pores in the coating and the capacitance of the coating, respectively. In many instances a constant phase element (CPE, designated as $Q$) describing the nonideal capacitive characteristics of the electrochemical interface is introduced to achieve a more accurate simulation of the corrosion reactions. The true nature of the CPE behavior is not clear; it is often attributed to the inhomogeneity and roughness of the electrode surface.\textsuperscript{16} The impedance of CPE may be defined by

$$\frac{1}{Z_{\text{CPE}}} = Z_0(j\omega)^n,$$

where $Z_0$ and $n$ are adjustable parameters representing the impedance constant and the empirical exponent, respectively. Here $n$ usually lies between 0.5 and 1; in the ideal case, $n = 1$ and $Z_0$ equals the capacitance.

### 3. Experiment

Silver-mirror samples based on the coating scheme in Fig. 1 were prepared by rf magnetron sputtering with and without a protective overcoat. For mirrors with a protective overcoat, the thickness of the NiCrN\textsubscript{x} interlayer was varied between 0 and 4Å. All films were
deposited in a cryopumped chamber equipped with four rf magnetron sputter guns employing 2 in. (1 in. = 2.54 cm) targets. The substrates were loaded onto a carousel that rotated at 20 rpm; 22 cubic centimeters per minute at standard temperature and pressure (SCCM) of Ar and 6.5 SCCM of N₂ flowed into the chamber, and the pump was throttled to achieve a pressure of 0.53 Pa (4.0 mTorr). Specific deposition parameters are given in Table 1. The substrates used were test-quality silicon wafers. Each layer's thickness was determined from the deposition time. Deposition rates were calibrated from thicker films by using optical and profilometer techniques.

The experimental setup for EIS is shown in Fig. 5. It was performed with a three-electrode cell (Gamry Instruments, PTC1 paint test cell) in which the mirror sample acts as the working electrode, a 6 mm diameter graphite rod as the counter electrode, and a saturated calomel electrode (SCE) as the reference electrode. The electrolyte, a 0.1 N NaCl aqueous solution, was not deaerated and tests were conducted at room temperature. EIS measurements were carried out with a Princeton Applied Research VMP2 multichannel potentiostat, using the free corrosion potential of individual mirror samples, a 20 mV peak-to-peak signal, and a frequency range from $10^4$ to $10^{-2}$ Hz. ZSimpWin, a commercially available software package from Princeton Applied Research, was used to compare EIS spectra with those of different equivalent electrical circuit models.

Humidity and salt fog testing were conducted in a Singleton Model SCCH-22 corrosion test chamber. The atmosphere for humidity testing was 49 °C and 95% relative humidity, and that for salt fog testing was 5% NaCl by weight and 35 °C. Samples exposed to salt fog were subsequently rinsed with deionized water and then blown dry with dry nitrogen. The specular reflectance of mirror samples was measured by using a Perkin-Elmer Lambda 9 UV–visible–near-IR scanning spectrometer equipped with a specular reflectance accessory. The incidence angle was 6° from normal. The absolute reflectance was determined by comparison with a National Institute of Standards and Technology traceable aluminum front-surface mirror. Surface morphology and elemental analysis of mirror samples were characterized with a JEOL 6460 scanning electron microscope equipped with an energy dispersive microanalyzer (EDS, INCAEnergy, Oxford Instruments).

### Table 1. Deposition Conditions for the Multilayer Silver-Mirror Coating

<table>
<thead>
<tr>
<th>Compound</th>
<th>Thickness (Å)</th>
<th>Rate (Å/s)</th>
<th>Target</th>
<th>rf Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiCrNₓ_n</td>
<td>8</td>
<td>0.027</td>
<td>80Ni–20Cr</td>
<td>20</td>
</tr>
<tr>
<td>Ag</td>
<td>1200</td>
<td>0.59</td>
<td>Silver</td>
<td>100</td>
</tr>
<tr>
<td>NiCrNₓ_n</td>
<td>0–4</td>
<td>0.027</td>
<td>80Ni–20Cr</td>
<td>20</td>
</tr>
<tr>
<td>SiNₓ</td>
<td>100</td>
<td>0.16</td>
<td>Silicon</td>
<td>200</td>
</tr>
</tbody>
</table>

The atmosphere for humidity testing was 49 °C and 95% relative humidity, and that for salt fog testing was 5% NaCl by weight and 35 °C. Samples exposed to salt fog were subsequently rinsed with deionized water and then blown dry with dry nitrogen. The specular reflectance of mirror samples was measured by using a Perkin-Elmer Lambda 9 UV–visible–near-IR scanning spectrometer equipped with a specular reflectance accessory. The incidence angle was 6° from normal. The absolute reflectance was determined by comparison with a National Institute of Standards and Technology traceable aluminum front-surface mirror. Surface morphology and elemental analysis of mirror samples were characterized with a JEOL 6460 scanning electron microscope equipped with an energy dispersive microanalyzer (EDS, INCAEnergy, Oxford Instruments).

### 4. Results and Discussion

The reflection spectra of different silver coatings are shown in Fig. 6. A bare-silver mirror exhibited a reflectance over 97% throughout most of the visible wavelengths, decreasing dramatically below 400 nm. Mirror samples with SiNₓ or SiNₓ/NiCrNₓ protective coating exhibited a faint yellowish tint. When 100 Å of SiNₓ was deposited on top of the silver film, the reflectance dropped ~1% at wavelengths longer than 550 nm and declined more rapidly to ~86% at 400 nm. The addition of a thin NiCrNₓ interlayer caused a slight additional drop in reflectance. It was possible to compensate for the absorption loss by adding a two-layer dielectric overcoat (504 nm silica and 480 nm titania) to enhance the short-wavelength reflection at the expense of the long-wavelength reflection. A sample with reflectivity enhancement layers is notated by peAg in Fig. 6.

Figure 7 shows the impedance spectra of four different mirror samples in Bode plots: A circuit model that generated the best fit to the EIS data of each sample was also given as a circuit description code (CDC). The impedance response of the bare-Ag coating exhibited the behavior of a simple corrosion...
The process of silver in contact with the NaCl solution. The Randles circuit provided a reasonably good fit to the impedance spectrum when the double-layer capacitor was replaced by a CPE. The spectrum for the SiN-coated Ag, on the other hand, was more complex. Double peaks in the phase-angle curve in Fig. 7(b) suggested that two time constants existed for the electrochemical process at the electrolyte–coating interface. Each time constant could be represented by one (R, C) pair in the equivalent circuit. A satisfactory fit was achieved with an equivalent circuit of a leaky capacitor in Fig. 4(b), with both capacitors in the model replaced by a CPE. This indicated that the SiN coating was porous and that ions in the electrolyte were capable of penetrating the coating to react with the silver. The impedance spectrum for the SiN/3Å NiCrN/Ag coating, differed again from that of the previous two coatings in that the phase-

Fig. 7. Electrochemical impedance spectra: (a) bare Ag, (b) SiN on Ag, (c) SiN on 1Å NiCrN on Ag, (d) SiN on 3Å NiCrN on Ag. The solid curves are calculated from equivalent circuit models shown in each plot with a CDC. CPEs (Q) were used in the models for better fitting.

Fig. 8. Variation of the low-frequency limit of the impedance magnitude of SiN/NiCrN/Ag mirrors with NiCrN interlayer thickness.
angle curve formed a plateau with phase angles close to $-90^\circ$. This behavior implied that the impedance response of the electrochemical interface was strongly capacitive. The EIS data were best described by using a simple serial RQ circuit model [Fig. 4(a), with the capacitor replaced by a CPE], suggesting that the dielectric coating on top of the silver was dense with minimum permeable defects. With 1Å of the NiCrN$_x$ interlayer, the phase-angle curve appeared to be in transition from that with no interlayer to the one with 3Å of nichrome nitride. It still showed the two-peak behavior, but the high-frequency peak was getting smaller while the low-frequency one broadened with higher phase angles. This implied that the SiN$_x$ topcoat became less permeable even with the extremely thin (1Å) NiCrN$_x$ interlayer.

In addition to the information generated from modeling, EIS data also provide an easy assessment of coating performance by examining the low-frequency limit of the impedance magnitude, $|Z|$. The low-frequency limit of $|Z|$ represents the resistance of a coating that impedes the flow of ions to the surface of

Fig. 9. Specular reflectance spectra of various silver coatings before and after 96 and 240 h humidity exposure: (a) bare Ag, (b) 100Å SiN$_x$ over Ag, (c) 100Å SiN$_x$ over 2Å NiCrN$_x$ over Ag, (d) 100Å SiN$_x$ over 4Å NiCrN$_x$ over Ag.
the metal substrates. It is, therefore, a good indicator of the corrosion-protection property of a coating. In practice, this is the value of $|Z|$ at the lowest frequency for which there is still no significant noise. As shown in Fig. 8, the impedance magnitude measured at 0.025 Hz for the silver-mirror samples increased with increasing thickness of the NiCrN$_x$ interlayer. The $|Z|_{0.025\,\text{Hz}}$ for the SiN$_x$/H$_2$O$_{862}$, 3Å–NiCrN$_x$/H$_2$O$_{862}$, Ag coating was almost 2 orders of magnitude higher than those for both the bare silver and the SiN$_x$-coated Ag without the interlayer.

The specular reflectance of different mirror samples before and after 96 and 240 h of humidity exposure is shown in Fig. 9. Bare-silver films showed considerable degradation in reflection after 96 h of humidity exposure, but only minimal further reflectance loss was measured after the 240 h test. However, the 240 h exposed samples appeared to be more severely corroded than those after the 96 h test, with many circular-shaped white corrosion spots 1 to 2 mm in diameter on the coating surface. Scanning electron microscopy (SEM) micrographs showed that these white spots consisted primarily of scattered blisters 5 to 30 µm in diameter (Fig. 10(a)). The corrosion spots were densely packed along the coating edges, and many of them had a pinhole or crack at the center. This suggested that water vapor penetrated the interface between the Ag film and the substrate along the coating edges or through the permeable defects, causing delamination and blistering of the coating. The loss in reflectance was partially due to scattered light from these blisters on the surface of the Ag film.

All mirrors with protective coatings performed well in the 96 h test with no reflection loss at wavelengths above 400 nm. However, many circular-shaped cracks developed on the SiN$_x$-coated Ag films in the 240 h test (Fig. 10(b)). The size of the cracks was comparable with that of the blisters on the bare Ag film. It appeared that blisters were formed initially during the humidity test in a way similar to those on the bare Ag film. Since SiN$_x$ was brittle, the SiN$_x$ coating over the blistered areas cracked and the blisters collapsed. White particles were clearly seen at the center of most of the cracks. EDS analysis on these particles showed considerable amounts of C (~20 at. %), O (~5 at. %), Cl (~7 at. %), and S (~0.5 at. %). These high levels of impurities were not expected since only deionized water and house air were used in the humidity test. The particles apparently grew out of corrosion reactions of exposed silver with...
certain types of contamination during the humidity testing.

Mirror samples with a NiCrN$_x$ interlayer showed improved performance in the 240 h humidity test. Not only did the reflection loss diminish, the size and number density of the cracks also decreased with increasing thickness of the interlayer. As shown in Fig. 10(c), the number of circular-shaped cracks on the SiN$_x$/H$_2$O$_{862}$2Å–NiCrN$_x$/H$_2$O$_{862}$Ag coating after 240 h of humidity exposure was less than both that of the blisters on the bare-Ag film and the cracks on the SiN$_x$/Ag coating. The size of the cracks on the SiN$_x$/2Å–NiCrN$_x$/Ag coating was also smaller, about 1.5 μm in diameter. Similar to the SiN$_x$/Ag coating, white corrosion particles existed at the center of the cracks. The SiN$_x$/4Å–NiCrN$_x$/Ag coating survived the 240 h humidity test well. The mirrors showed no noticeable corrosion spots under the naked eye. The reflection loss was within 1% over the entire visible range, and only a few small cracks were observed under SEM [Fig. 10(d)].

Figure 11 shows the reflection spectrum of mirror
samples before and after 24 and 72 h exposure to salt fog. The salt spray test is a much more severe test than the humidity test. Both the bare-Ag and the SiN$_x$-coated Ag mirrors tarnished significantly, with extensive reflection loss after 24 h of salt fog exposure. The tarnish layer on bare Ag appeared as circular dark gray dots on a light brownish background, with the dots more densely packed in areas along the edges. The tarnish on the SiN$_x$-coated Ag film, on the other hand, was mostly light brown in color. Although the two tarnished films looked different, their specular reflections were about the same, suggesting that the reduction in reflectance after salt fog testing might be due mostly to scattering of light from the corrosion products. SEM micrographs of 72 h exposed samples showed that both coatings corroded uniformly as the reaction product grew into micrometer-sized crystallites [Figs. 12(a) and 12(b)]. The average size of the crystallites was smaller in the dark gray dots than in the brownish areas, and the number density appeared to be higher. In addition, it is evident that the number density of the crystallites on the two coatings is extensively higher than that of the blisters on similar samples exposed to 240 h of humid air. Therefore the reflection loss of the two salt fog tested samples were much greater than those subjected to the humidity test.

EDS analysis of the crystallites on both the bare-Ag and the SiN$_x$-coated Ag films indicated that the crystallites were rich in silver and only a small amount of chlorine was detected (Table 2). EDS results on areas surrounding the crystallites revealed lower silver concentrations when compared with a pristine bare-Ag coating. These results suggested that the crystallites were silver grains generated dur-

![Fig. 12. SEM micrographs of various silver coatings after 72 h salt fog exposure: (a) bare Ag, (b) 100Å SiN$_x$ over Ag, (c) 100Å SiN$_x$ over 1Å NiCrN$_x$ over Ag, (d) 100Å SiN$_x$ over 3Å NiCrN$_x$ over Ag.](image)

<table>
<thead>
<tr>
<th>Table 2. EDS Elemental Analysis of Bare-Ag Mirrors before and after the 72 h Salt Fog Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concentration (at. %)</strong></td>
</tr>
<tr>
<td>EDS Analyzed Area</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Ag film—pristine</td>
</tr>
<tr>
<td>Ag film—after 72 h salt fog exposure</td>
</tr>
<tr>
<td>Crystallite—after 72 h salt fog exposure</td>
</tr>
</tbody>
</table>
ing salt fog exposures at the expense of the Ag film in the surrounding areas. It was conceivable that the corrosion reactions of silver exposed to the salt fog involved the dissolution of Ag into the surface layer of the salt solution, precipitation of AgCl on the silver surface, and photoreduction of AgCl back into metallic Ag, since the salt fog test was conducted under continuous fluorescent lighting and the testing chamber had a transparent acrylic cover. The fact that the 100Å SiNx-coated Ag film exhibited similar morphology to the bare-Ag coating after the salt fog test suggested that the SiNx overcoat was porous such that the salt solution penetrated the film, reacted to the Ag film, and resulted in the growth of Ag crystallites through open pores or microcracks.

With just 1Å of the NiCrNx interlayer between the Ag and the SiNx overcoat, the film showed a dramatic improvement in corrosion performance against the attack of salt fog. Almost no loss in reflectance was observed after 24 h of salt fog exposure, and less than a 3% loss in reflectance after 72 h testing. The SEM micrograph in Fig. 12(c) also shows a significant reduction in both the number density and size of Ag crystallites. The SiNx/3Å–NiCrNx/Ag film provided the best corrosion resistance against salt fog, with almost no loss in mirror reflection and minimal crystallite formation after exposure to salt fog for 72 h [Figs. 11(d) and 12(d), respectively].

The variation in the specular reflectance change of mirror samples with different thickness of the NiCrNx interlayer after humidity and salt fog testing is shown in Fig. 13. Both tests clearly demonstrated that mirrors with a nichrome nitride interlayer performed much better than those without the interlayer. These results correlated well with the EIS data. All three experiments led to the conclusion that the SiNx film by itself was permeable to corrosion media, such as aqueous electrolytes, humid air, or salt fog, and afforded limited protection to the underlying Ag. The incorporation of a thin NiCrNx interlayer performed much better than those without the interlayer. These results correlated well with the EIS data. All three experiments led to the conclusion that the SiNx film by itself was permeable to corrosion media, such as aqueous electrolytes, humid air, or salt fog, and afforded limited protection to the underlying Ag. The incorporation of a thin NiCrNx interlayer performed much better than those without the interlayer. These results correlated well with the EIS data.

The mechanism behind the additional protection is intriguing. It is generally known that the growth of thin films from vapor deposition is a process of heterogeneous nucleation and coalescence. Islands grow from individual nuclei until they touch each other to form a continuous network; this transition can be characterized by a percolation threshold thickness. The mean percolation thickness is usually between 1 and 20 nm. The thickness of the SiNx film is right in the middle of the percolation threshold. It is not surprising that such a film contains a high density of defects such as voids and open pores. In our earlier research, the TEM of a silver coating with an 8Å NiCrN film, interlayer showed no evidence of NiCrN island formation. However, Wolfe demonstrated that the 8Å NiCrN, interlayer in their coating formed islandlike agglomerates along the Ag/SiNx interface and suggested that these agglomerates might be a new phase that provided the exceptional barrier properties for corrosion protection. In any case it is hard to imagine that a 1–3Å NiCrNx film would form a continuous barrier layer that provides the additional corrosion protection for the underlying Ag film. We hypothesize that the ultrathin NiCrNx interlayer is still in the form of isolated islands that provide considerably more nucleation sites for SiNx film growth relative to bare silver. In the presence of many nucleation sites, subsequent deposition of atoms need not diffuse far before finding a new low-energy site on the growing film. The islands are closer to each other, and the coalescence process is completed more rapidly, decreasing shadow effects that might accentuate void formation. In this way, the resultant silicon nitride film is much denser with minimum permeable defects.

5. Conclusions

Electrochemical impedance spectroscopy, humidity testing, and salt fog testing were applied to the study of the corrosion behavior of a durable silver-mirror coating scheme designed by Wolfe et al. The protective coating in the mirror design consisted of an ultrathin NiCrNx interlayer between the Ag film and a 100Å layer of silicon nitride. Analysis of EIS data
with equivalent circuit models suggested that the SiN topcoat was porous when there was no NiCrN interlayer and that the electrochemical response of the SiN-coated Ag coating acted as a “leaky capacitor.” When a 3Å thick NiCrN interlayer was added, the impedance response of the coating became strongly capacitive and the low-frequency impedance limit increased by 2 orders of magnitude in comparison with the one without the interlayer. The results obtained from both humidity and salt fog testing correlated well with EIS data. All three tests revealed that the SiN overcoat alone was porous and provided limited corrosion protection to the underlying Ag film, whereas the SiN/3Å-NiCrN/Ag coating exhibited excellent corrosion resistance, showing essentially no change in reflection after 72 h of exposure to the salt fog. As it was unlikely for a 3Å thick sputtered NiCrN coating to form a continuous barrier layer for enhanced corrosion protection, we concluded that the NiCrN interlayer played a crucial role in facilitating the growth of a dense, and hence protective, SiN overcoat by providing many nucleation sites.

This research was supported under The Aerospace Corporation’s Mission Oriented Investigation and Experimentation program, funded by the U.S. Air Force Space and Missile Systems Center under contract FA8802-04-C-0001. The authors thank Albert Zimmerman and Michael Quinzio for their support with the impedance measurements, Gary Steckel and Ben Nelson for their help with the humidity and salt fog testing, Christopher Lim and Kelsey Folgner for their assistance in the experiments, and Sergio De La Torre for SEM micrographs and EDS analysis (all from The Aerospace Corporation).

References
学霸图书馆

www.xuebalib.com

本文献由“学霸图书馆-文献云下载”收集自网络，仅供学习交流使用。

学霸图书馆（www.xuebalib.com）是一个“整合众多图书馆数据库资源，提供一站式文献检索和下载服务”的24小时在线不限IP图书馆。

图书馆致力于便利、促进学习与科研，提供最强文献下载服务。

图书馆导航：

图书馆首页 文献云下载 图书馆入口 外文数据库大全 疑难文献辅助工具