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Dear Prof. Kobayashi,

I am herewith submitting an article entitled "**Double layer SiO₂/Al₂O₃ high emissivity coatings on stainless steel substrates using simple spray deposition system**", by Mahadik et al. for intended publication in *Applied Surface Science* using on-line web-submission tool. Kindly acknowledge the receipt of the same. We also enclose the list of potential reviewers.

Thanking you and with kind regards,

Yours sincerely,

(Harish Barshilia)

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*Highlights (for review)

1. Sol-gel process was used to develop high emissivity $\text{SiO}_2/\text{Al}_2\text{O}_3$ coatings.
2. A maximum emittance of 0.94 and a minimum absorptance of 0.30 were achieved.
3. Reflectance <1 % achieved in the wavelength range of 2.5-25 μm .
4. The coatings exhibited thermal stability up to 1000°C in air.

Double layer SiO₂/Al₂O₃ high emissivity coatings on stainless steel substrates using simple spray deposition system

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Abstract

High emissivity coatings are widely used in spacecraft and industrial furnaces, which have attracted a great attention recently due to energy saving applications. In this study, a simple spray coating method was used to produce double layer high emissivity coatings on stainless steel (SS) substrate by sol-gel process at room temperature. Initially silica (SiO₂) sol, prepared using sol-gel process, was deposited on sandblasted SS substrate with required thickness, followed by deposition of aluminium oxide (Al₂O₃) layer. The gradual increase in the thickness of Al₂O₃ layer resulted in increase in the emittance. The optimized double layer Al₂O₃ (23 μm)/SiO₂ (9.13 μm) coating on SS substrate exhibited high emittance ($\epsilon = 0.92-0.94$) and low absorptance ($\alpha = 0.30-0.34$). The high emissivity coating, when exposed to a temperature of 1000 °C in air, showed nearly the same value of emissivity. The SiO₂/Al₂O₃ coating thus provides a simple and cost effective method for the preparation of high emissivity coatings.

Keywords: Sol-gel, spray deposition system, SiO₂/Al₂O₃ coating, high emissivity

1. Introduction

High emissivity coatings have received a great attention recently, especially for spacecraft applications [1,2], radiative cooling applications [3] and electrical insulation [4]. These coatings provide enhanced radiant heat transfer from refractory surfaces, allowing a substantial reduction in energy cost and emissions in direct-fired furnaces [5-6]. The solar cells on spacecraft are exposed to very harsh thermal environment during friction between space vehicle surface and atmosphere, which seriously affect the lifetime and performance of solar cells on spacecrafts [7-8]. Therefore, thermal radiative properties of surface coatings are important because as the temperature increases, conversion efficiency of the solar cells and life time of material decreases. Hence, high emissivity coating is deposited on spacecraft to decrease the surface temperature by the radiation. These coatings effectively transfer the heat by radiation [9]. Applying a high-emissivity coating on the furnace wall increases the net temperature in the interior of the furnace, and which ultimately helps to save power [10-11]. Shioya et al. [12] have reported 13% energy saving in fuel consumption, after application of high emissivity (0.90) coating inside the furnace.

Emittance (ε) is an important material property that enables determining the emissive power of a real body. The emittance depends on the reflectance (R) and transmittance (τ) of the material, which, in turn, depends on temperature (T) of the material and wavelength (λ) of the radiation. According to Kirchhoff's law for perfectly opaque bodies $\varepsilon = 1 - R$. The emittance here is characterized to describe the surface radiative property which involves the transfer of heat by electromagnetic radiation arising due to the temperature of a body. The total normal emissivity at room temperature, is calculated by integrating spectral reflectance in the spectral region of 2.5-25 μm wavelength and is expressed as: [3,12]

$$\varepsilon(T) = \frac{\int_{2.5}^{25} \{1 - R(\lambda, \theta=0)\} i_b(\lambda, T) d\lambda}{\int_{2.5}^{25} i_b(\lambda, T) d\lambda}, \quad (1)$$

where θ is incident angle, $i_b(\lambda, T)$ is the spectral intensity of a blackbody at temperature T . This spectral region includes emissive power of a body at room temperature. Hence low reflectance in far infrared region centered around 10 μm produces high emissivity at room temperature. The emissivity study in this spectral region is usually used for thermal design of spacecraft [13].

In the literature, many high emissivity coatings are reported for thermal protection of solar cells, spacecrafts and energy saving application for industrial furnace to lower the surface temperature by various deposition methods. Kazomori et al. [1] have reported that the emissivity increases to 0.77 by applying $\text{SiO}_2/\text{Al}_2\text{O}_3$ coating on solar cell thin films by e-beam evaporation. Hui Tang et al. [14-15] have reported coatings by micro-arc oxidation of titanium alloy, which shows high emissivity of 0.90. Jianping et al. [7] have prepared the cauliflower like microstructured CeO_2 coatings by e-beam evaporation, which show an emissivity of 0.90 at 873K in the mid-infrared spectral range. Some authors have used sol-gel process for synthesis of high emissivity coatings on different substrates. For example, Zhao et al. [8] have reported that the carbon nanotubes doped $\text{SiO}_2/\text{SiO}_2\text{-PbO}$ double layer coatings show high emissivity of 0.94. Similarly, Chelashaw et al. [16] have reported high emissivity (0.91-0.94) by dispersing ceramic nano-particles in Al_2O_3 sol matrices, prepared by sol-gel spray coating method. Holcombe et al. [17] have applied high emissivity coating for coating the interior of a furnace to direct thermal energy toward a load in the furnace. Similarly, Heynderickx et al. [18] reported 5% increase in the performance by applying high emissivity coating on the pyrolysis furnace. Various techniques such as chemical vapour deposition and physical vapour deposition have been used to deposit high emissivity coatings. However, most of these methods are costly and require vacuum, targets of high purity and high processing temperature. Therefore, attempts have been made to develop high emissivity coatings by simple sol-gel process at room temperature using spray deposition system.

In recent years, sol-gel method has been receiving a great deal of attention among the scientists and engineers working in the field of nanomaterials due to the relative ease and reliability of the sol-gel methods in the synthesis and processing of nanomaterials with high degree of purity. The other advantages of the sol-gel processing are the cost reduction, made possible by the lower temperatures involved, porosity control, and relatively less expensive instrumentation and techniques required for the synthesis [19-20]. Though there are variety of methods available for deposition of high emissivity coatings, simple and cost effective processes like spray or dip coating method could be used to deposit films on substrates of arbitrary shape, and is easily adaptable to industrial scale. Porous structure, which is expected to improve coating's emissivity by creating much more reflecting interfaces [21], is prepared by hybrid sol-gel method.

This paper presents the development of high emissivity coating of $\text{SiO}_2/\text{Al}_2\text{O}_3$ on sandblasted stainless steel substrate using spray deposition system. Thickness of SiO_2 layer was optimized and then thickness of Al_2O_3 was optimized to achieve high emittance and low absorptance coating. For the optimized process parameters, (i.e., sol-gel parameters, thickness) high emittance value (0.94) in the infrared region and low absorptance (0.30) in the visible region have been achieved for this $\text{SiO}_2/\text{Al}_2\text{O}_3$ coating. Several characterization techniques were used to study the optical properties and structural characteristics of the prepared $\text{SiO}_2/\text{Al}_2\text{O}_3$ coatings. Solar spectrum reflectometer and emissometer were used to measure the absorptance and emittance of the coating, respectively. Fourier transform infrared spectrometer was used to determine the reflectance in the 2.5-25 μm wavelength region. X-ray diffraction (XRD), 3D profilometer, X-ray photoelectron spectroscopy (XPS), and field emission scanning electron microscopy (FESEM) were used to study the structural and chemical characteristics of the high emissivity coatings. To check the thermal stability of

SiO₂/Al₂O₃ high emissivity coatings, heat treatment of the optimized sample has been carried out in air for 2 hrs at 1000°C. A superalloy substrate was used for these studies.

2. Experimental details

The samples were prepared on sand-blasted SS304 substrates. In sand blasting process, a smooth surface is converted into a rough surface to enhance the emissivity and adhesion of the coating material. The sand blasting has been carried out for about 3 min, which induces a root mean square roughness of 2.9 μm. It may be noted that sandblasted bare SS substrates showed an emittance of 0.63 and an absorptance of 0.45. Thus prepared rough samples of 304L stainless steel were cleaned and used for deposition of SiO₂ and Al₂O₃ coatings.

For the preparation of coating sol the following chemicals were used: tetraethylorthosilicate (TEOS), (3-glycidyoxypropyl) trimethoxysilane (GPTMS) and aluminum tri-*sec*-butoxide (Al(O-*sec*-Bu)₃) (Sigma–Aldrich Chemie, Germany), ethanol, ethyl acetoacetate and isopropyl alcohol (*i*-PrOH) (S.D. Fine Chem Ltd.). Milli-Q water was used for preparation of diluted hydrochloric and acetic acid catalysts. The SiO₂ sol was prepared using TEOS diluted in ethanol. Acidic water in the form of hydrochloric acid (0.001 M HCl) was added to this solution and continuously magnetically stirred for 24 hrs at room temperature for complete hydrolysis [22]. The molar ratio of TEOS: EtOH: H₂O is 1:40:2. The resulted sol was used for deposition after 24 hrs aging at room temperature. Al(O-*sec*-Bu)₃ and isopropyl alcohol were mixed and magnetically stirred at room temperature for 1 hr. Ethyl acetoacetate was added to the solution as a chelating agent to control the rate of reaction and solution was continuously magnetically stirred for 24 hrs [23]. After stirring, water diluted with *i*-PrOH was carefully added drop wise to the solution for hydrolysis and continued stirring for 2 hrs. The molar ratios of *i*-PrOH, EAcAc, and H₂O to Al(O-*sec*-Bu)₃ were 20, 1 and 2, respectively.

In order to improve the adhesion of Al_2O_3 coating a binder sol having GPTMS and TEOS in molar ratio 1:1 with ethanol solvent and 1M acetic acid catalyst were used. Ethanol and water to silane ratios were 11 and 2, respectively. The sol was magnetically stirred for 24 hrs for complete hydrolysis. This sol was added to Al_2O_3 sol and magnetically stirred for 5 hrs to mix thoroughly in Al_2O_3 sol and finally used for deposition.

First, SiO_2 layer was deposited on sandblasted stainless steel substrate using simple spray coating process at room temperature. The air pressure of the spray deposition system was kept at 0.5 bar and the number of passes (4, 6, 8 and 10) of spray gun of SiO_2 sol were used to get different thicknesses (2.2, 6.21, 9.13 and 13.4 μm). After deposition of SiO_2 layer the substrates were dried at 100°C in air atmosphere for 1 hr for densification of the network and evaporation of the solvent. The thickness of SiO_2 coating increased with increasing the number of passes of spray gun. A maximum emittance of 0.84 and absorptance of 0.78 were obtained for SiO_2 coating with a thickness of 9.13 μm . This thickness was used for further deposition of Al_2O_3 layer. Then, second layer of Al_2O_3 was deposited having a thickness of 4.87, 13.4, 16.2, 20.7, 23 μm on optimized SiO_2 coated SS substrates. These samples were further annealed in air at 100°C for 1 hr. The emittance of the $\text{SiO}_2/\text{Al}_2\text{O}_3$ coatings was increased from 0.84 to 0.94 and absorptance was decreased from 0.78 to 0.33. It is well known that the SiO_2 shows high emissivity (~ 0.84) in mid infrared region. To develop high emissivity and low absorptance coating second layer of Al_2O_3 was deposited due to its suitable optical properties, i.e., low extinction coefficient and low absorptance in wavelength region 2.5 to 25 μm . The schematic model of $\text{SiO}_2/\text{Al}_2\text{O}_3$ double layer high emissivity coating is shown in Fig. 1.

The absorptance and emittance of the high emissivity coatings were measured using solar spectrum reflectometer (Model SSR) and emissometer (Model AE) of M/s. Devices and Services. The absorptance and the emittance values were measured at three different positions

and the values reported herein are the average of four measurements. Reflectance of the samples was measured using Spectrum-GX FTIR spectrometer from PerkinElmer. The XRD patterns of the coatings were recorded using X-Ray diffractometer (Bruker D8) having thin film attachment. Cu K α radiation ($\lambda = 0.154$ nm), operated at 40 kV and 40 mA, was used as X-ray source. The microstructural and morphological details of the coatings were investigated using Supra 40 VP, Carl Zeiss high resolution field emission scanning electron microscopy (FESEM). Thickness of the coatings was measured with the help of a NanoMap500LS 3D Profilometer. The bonding structure of the coatings was characterized by XPS (SPECS) using non-monochromatic Al K α radiation (1486.8 eV). The binding energies reported here were calculated with reference to C1s peak at 284.6 eV with a precision of 0.1 eV. In order to test the thermal stability, SiO₂/Al₂O₃ high emissivity coatings, deposited on alloy, were heated in air fired tubular furnace at 1000°C temperature for 2 hrs. Changes in the absorptance and emittance of the samples after heat treatment were studied.

3 Results and discussion

3.1 Single/double layer SiO₂ and Al₂O₃ coatings

Cleaned stainless steel substrates after sand blasting process were used to deposit SiO₂ coating by spray deposition method. The thickness of SiO₂ coating was increased with increasing the number of passes of spray gun. The thickness of SiO₂ coating was found to increase from 2.2 to 13.4 μ m for an increase of passes of the spray gun from 4 to 10. Fig. 2 showed the variations of emittance ' ϵ ' and absorptance ' α ' values, with increasing thickness of SiO₂ coating. It is observed that as thickness increases the emittance increases from 0.82 to 0.89 with nearly a constant absorptance values 0.77-0.78. The enhancement of emissivity by increasing the SiO₂ thickness is therefore limited. It may be noted that at coating thickness greater than 13 μ m, the SiO₂ coatings exhibited large cracks presumably because of increased

stress level. Therefore, SiO₂ coating thickness of 9.2 μm was used for further deposition of second layer.

When the radiation falls on a body, it may be partially reflected, transmitted or absorbed. The light penetration depth 'd_p' is closely related to the emissivity of coating, which in turn depends on the wavelength (λ) of the light and the extinction coefficient (k) [3],

$$d_p = \frac{1}{\alpha} = \frac{\lambda}{4\pi k}. \quad (2)$$

This equation suggests that *k* should be as low as possible to increase the penetration depth. Therefore, a material which has high penetration depth is required to achieve high emissivity. SiO₂ has a low extinction coefficient, and single layer of SiO₂ itself showed maximum high emittance up to 0.84 with good adhesion with SS substrate but absorptance of this layer was high (0.78). Al₂O₃ is a well known material with very low extinction coefficient [24]. Therefore, a thick layer of Al₂O₃ material was selected for the deposition of second layer on the SiO₂ coated SS substrate to decrease the absorptance of SiO₂ coating and increase the overall emittance. The variations of emittance and absorptance with respect to thickness of Al₂O₃ coating on SiO₂ coated samples are shown in Fig. 3. With increasing thickness of Al₂O₃ from 4.87 μm to 23.0 μm the emissivity increases from 0.84 to 0.94. The optimized coating of SiO₂/Al₂O₃ double layer showed high emittance of 0.94 and absorptance of 0.33 at room temperature. Fig. 4 shows photographs of SiO₂ coated and Al₂O₃ coating on SiO₂ coated sandblasted stainless steel substrate with emittance and absorptance values. Hence these high emissivity and low absorptance coatings are useful in heating furnace for energy saving purpose as well as in spacecraft applications [25-26].

3.2 Reflectance measurement studies

Fig. 5 shows the measured spectral reflectance data of SiO₂ and Al₂O₃ coatings deposited on sandblasted SS substrates. The single layer of SiO₂ and Al₂O₃ coatings show an average 13-14 % reflectance in the wavelength 2.5 to 25 μm region. These data indicate that

the single layers of either SiO₂ or Al₂O₃ cannot produce a coating with high emittance. Therefore, a double layer of SiO₂ and Al₂O₃ was used to lower the over reflectance (thus high emittance) in the wavelength 2.5 to 25 μm region. Fig. 6 shows spectral reflectance of Al₂O₃ deposited on SiO₂ coated sandblasted SS samples in the wavelength region from 2.5 to 25 μm with varying thickness of Al₂O₃ layer. It is observed that as the thickness of Al₂O₃ increases to 23.0 μm the reflectance decreases to as low as ~0.2%. According to Wein's displacement law [27], $\lambda_{\max}T = 2897.8 \mu\text{m K}$, where T is temperature. At room temperature λ_{\max} is 9.66 μm. The reflectance of the material around $\lambda \sim 10 \mu\text{m}$ should be minimum to get high emissivity at room temperature. It is observed from the reflectance data SiO₂/Al₂O₃ double layer coating has a very low reflectance (0.2%) in the wavelength region of 8-15 μm, which yields to high emissivity of the coating. This low reflectance coating is essential to increase the emittance due to thickness of coating and low extinction coefficient of Al₂O₃ [28].

3.3 *Microstructural and structural characterization*

The surface morphologies of single layer SiO₂ coating obtained by FESEM are shown in Fig. 7(a) and (b). Fig. 7(a) showed that micro-cracks (width of ~1.5 μm) are uniformly distributed on sol-gel spray deposited SiO₂ coating having a thickness of ~6.15 μm. These micro-cracks are observed may be due to the solvent evaporation while spray deposition. The magnified image of SiO₂ coating is shown in Fig. 7(b), which showed a uniform and smooth surface. The FESEM micrograph of single layer Al₂O₃ coating with a thickness of ~23.0 μm is shown in Fig. 7(c). It is seen that Al₂O₃ coating surface is rough and has micro-cracks of ~10 μm in width. Fig. 7(d) is the magnified image of Al₂O₃, coating, which showed random cluster growth. Also big pores are observed in the coating. The surface roughness profile and 3-D profilometry image of a double layer SiO₂ (9.14 μm)/Al₂O₃ (23.0 μm) coating deposited on sandblasted SS substrate is shown in Figs. 7(e) and 7(f), respectively. The line profiles were measured at three locations. It is observed that SiO₂/Al₂O₃ coating showed the

repeatable V shaped grooves like surface profile. The average root mean square surface roughness (σ) calculated from these scans was $\sim 6.9 \mu\text{m}$.

The emissivity depends on surface roughness and material properties. For a real surface, the roughness is characterized by the ratio of σ to λ , (i.e., σ/λ). This ratio is generally divided into three regions, namely, (i) specular region ($0 < (\sigma/\lambda) < 0.2$), geometric region ($(\sigma/\lambda) > 1$) and intermediate region ($0.2 < \sigma/\lambda < 1$). For the optimized double layer $\text{SiO}_2/\text{Al}_2\text{O}_3$ coating, the σ/λ ratio lies in between 0.26-2.6 in the 2.5 to 25 μm wavelength region. Hence, σ/λ ratio of the $\text{SiO}_2/\text{Al}_2\text{O}_3$ coating mainly lies in the geometric region. The enhancement in the emissivity of the coatings in the geometric region has been explained by geometric optics, especially using the V-shaped grooves [3]. The slope of the V shaped grooved surface plays an important role in an emissivity enhancement for $\sigma/\lambda > 1$. For V shaped groove, the inter-reflection of incident light will be more, could significantly enhance the normal emissivity of the coating. The surface line profiles of the samples of the present study thus suggest that the V shaped grooves contribute significantly in enhancing the overall emissivity of the $\text{SiO}_2/\text{Al}_2\text{O}_3$ coating.

The silicon substrate was deposited with single layer SiO_2 and Al_2O_3 coatings for XRD measurements. X-ray diffraction patterns of the SiO_2 (7.2 μm thickness) and Al_2O_3 (23 μm thickness) coatings are shown in Fig. 8. It can be concluded from the absence of peaks in the SiO_2 pattern, that the SiO_2 coating synthesized by sol-gel method is purely amorphous in nature [29-30]. Also, as it is seen from the X-ray diffraction pattern of the Al_2O_3 , the broad peak from 13-20° angle confirms the amorphous nature of the alumina film [31]. The sharp peak at $2\theta = 55.6^\circ$ is from the silicon substrate.

X-ray photoelectron spectroscopy was used to study the bonding structure of sol-gel synthesized SiO_2 and Al_2O_3 coatings. The survey scan spectra confirmed the presence of Si, Al and O in the SiO_2 and Al_2O_3 coatings and are shown in Figure 9. The presence of silicon

in the Al_2O_3 coating was also observed from the survey spectrum and this may be originated from the silicon substrate. This is because, the sol-gel synthesized Al_2O_3 coatings are highly porous in nature and it was confirmed from the FESEM micrographs (Fig.7(d)). Figure 10(a) and (b) shows the core level high-resolution XPS spectra of the single layer SiO_2 coating. The Si $2p$ (Fig. 10(a)) and O $1s$ spectra (Fig. 10(b)) showed characteristic peaks at 102.86 and 532.16 eV, which correspond to Si-O bonding [32-33]. Similarly, the Al $2p$ (Fig. 10(c)) and O $1s$ spectra (Fig. 10(d)) showed characteristic peaks at 74.30 and 531.50 eV, which correspond to Al attached to oxygen (i.e., Al_2O_3) [34].

3.4 Thermal stability of $\text{SiO}_2/\text{Al}_2\text{O}_3$ coating in air

In order to test the thermal stability of double layer $\text{SiO}_2/\text{Al}_2\text{O}_3$ high emissivity coatings at higher temperature ($\sim 1000^\circ\text{C}$) a superalloy substrate was used. Due to substrate limitation, we have not measured thermal stability above 1000°C . This $\text{SiO}_2/\text{Al}_2\text{O}_3$ coating deposited on superalloy exhibited $\varepsilon = 0.94$ and $\alpha = 0.34$ before heat treatment. This sample was heat-treated at 1000°C in air atmosphere for 2 hrs in a resistive heating furnace. After heat-treatment, the samples exhibited an emittance of 0.92 and an absorptance of 0.42. There is little difference observed in emissivity value, which may be attributed to the densification of the network and decomposition of carbohydrate groups [35]. Hence, this study confirms the $\text{SiO}_2/\text{Al}_2\text{O}_3$ coatings are thermally stable at 1000°C in air atmosphere. The high thermal stability of the $\text{SiO}_2/\text{Al}_2\text{O}_3$ coating is attributed to the fact that both SiO_2 and Al_2O_3 are highly stable thermally. SiO_2 is formed by directional covalent bonds, and has a well-defined local structure with a melting point of $\sim 1400^\circ\text{C}$ [36]. Similarly, Al_2O_3 is formed by strong ionic bonds, having melting point of $\sim 2072^\circ\text{C}$ [37]. As both the oxides have high thermal stability, hence $\text{SiO}_2/\text{Al}_2\text{O}_3$ double layer coating can be stable up to a temperature of $\sim 1300^\circ\text{C}$. Also due to the presence of strong bonding in both oxides interdiffusion or mixing of layers is not expected to occur at high temperature.

This work has scope for further improvement in enhancing the emittance from 0.94 to ~0.97 and decreasing the absorptance value from 0.33 to ~0.2. This can be achieved by increasing the emittance of single layer SiO₂ up to 0.90, by doping nanoceramic particles or carbon nanotubes in this layer [7]. The Al₂O₃ layer deposited on such SiO₂ coating can further enhance the emittance up to 0.97 and reduce the absorptance less than 0.20 [17].

4. Conclusion

The double layer SiO₂/Al₂O₃ coatings were deposited on sandblasted SS substrate using spray deposition system at room temperature. Simple and cost effective sol-gel method was used to prepare SiO₂ and Al₂O₃ sols. The optimized SiO₂/Al₂O₃ coating shows high emittance (0.94) and low absorptance (0.30). The double SiO₂/Al₂O₃ coating showed very low reflectance (0.2%) around 10 μm wavelength region, which is attributed to high emissivity of the coatings. Surface morphology of SiO₂ coating exhibited cracks and Al₂O₃ morphology was significantly rough with random cluster growth. The XRD data of the sol-gel prepared SiO₂ and Al₂O₃ materials indicated their amorphous nature. The chemical bonding was further confirmed using XPS. SiO₂/Al₂O₃ double layer high emissivity coatings were thermally stable at 1000°C in air. Hence, the double layer SiO₂/Al₂O₃ coating gives the high emissivity and low absorptance values within the permissible temperature range with very simple and cost effective method of preparation and freedom to coat any size of substrate, which could be useful in furnace and spacecraft applications.

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Figure Captions:

Fig. 1. Schematic diagram of the SiO₂/Al₂O₃ double layer high emissivity coating deposited on stainless steel substrate.

Fig. 2. Plot of emittance and absorptance versus thickness of single layer SiO₂ coatings.

Fig. 3. Plot of emittance and absorptance versus thickness of Al₂O₃ coating on 9.13 μm thick SiO₂ layer deposited on sandblasted SS substrates.

Fig. 4. Photographs of (a) SiO₂ (b) SiO₂/Al₂O₃ coated sandblasted SS substrates.

Fig. 5. Reflectance spectra of single layer SiO₂ and Al₂O₃ coatings on sandblasted SS sample in the wavelength range of 2.5-25 μm.

Fig. 6. Reflectance spectra of SiO₂/Al₂O₃ double layer coatings for 4.78 - 23 μm thickness of Al₂O₃ layer. The SiO₂ layer thickness was 9.13 μm.

Fig. 7. FESEM micrographs of: (a) SiO₂ coating with low magnification, (b) SiO₂ coating with high magnification, (c) Al₂O₃ coating with low magnification, (d) Al₂O₃ coating with high magnification, (e) Surface roughness profile of optimized SiO₂/Al₂O₃ coating and (f) 3-D profile of the SiO₂/Al₂O₃ coating.

Fig. 8. X-ray diffraction patterns of SiO₂ and Al₂O₃ coating deposited on silicon substrates.

Fig. 9. Wide XPS spectra of SiO₂ and Al₂O₃ coatings deposited on silicon substrates.

Fig. 10. Core level spectra of: (a) Si 2p (b) O 1s of SiO₂ coating, and (c) Al 2p and (d) O 1s of Al₂O₃ coating.

Fig. 1

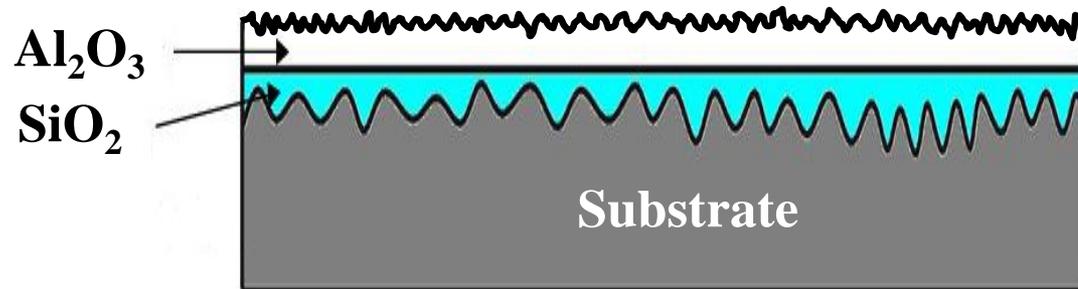


Fig. 2

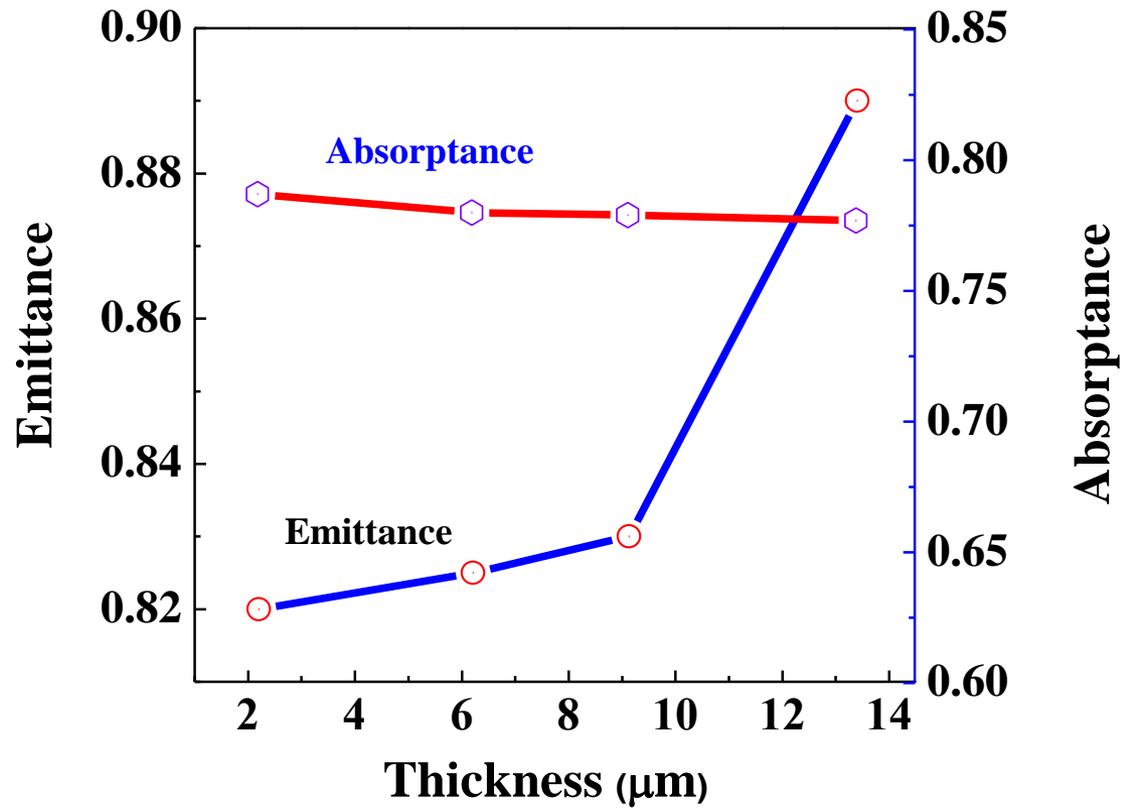


Fig. 3

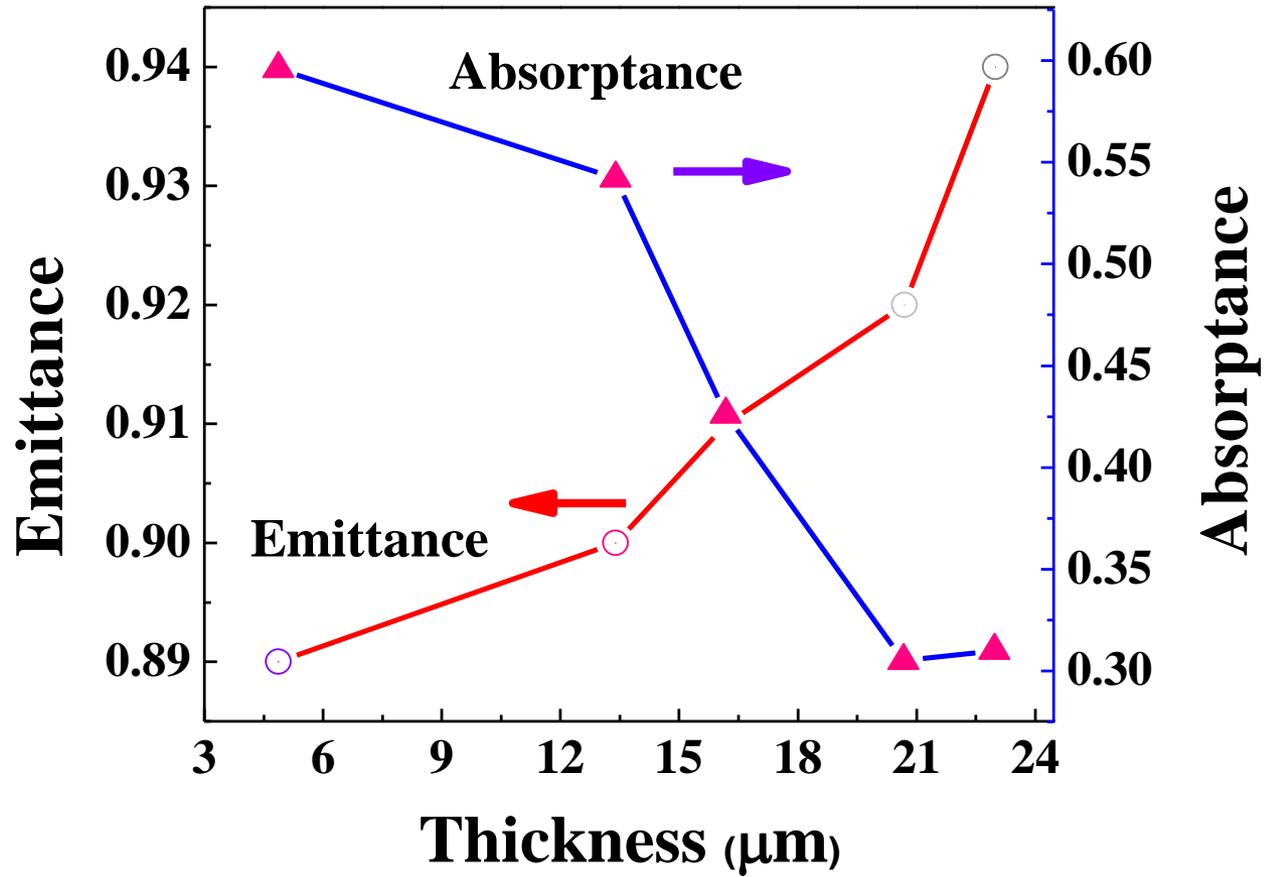


Fig. 4

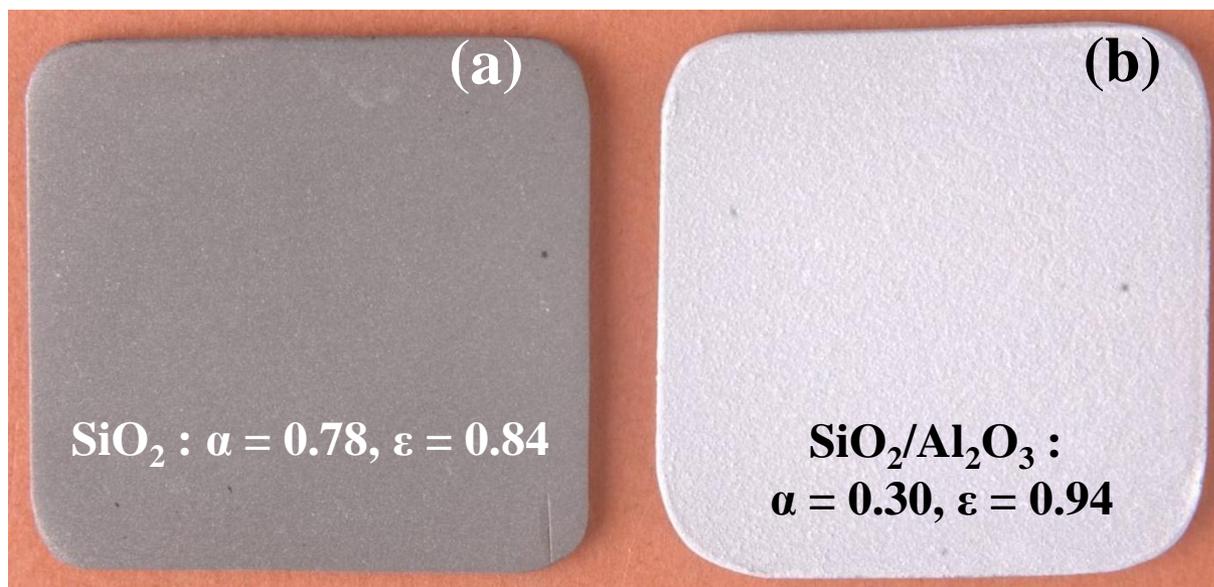


Fig. 5

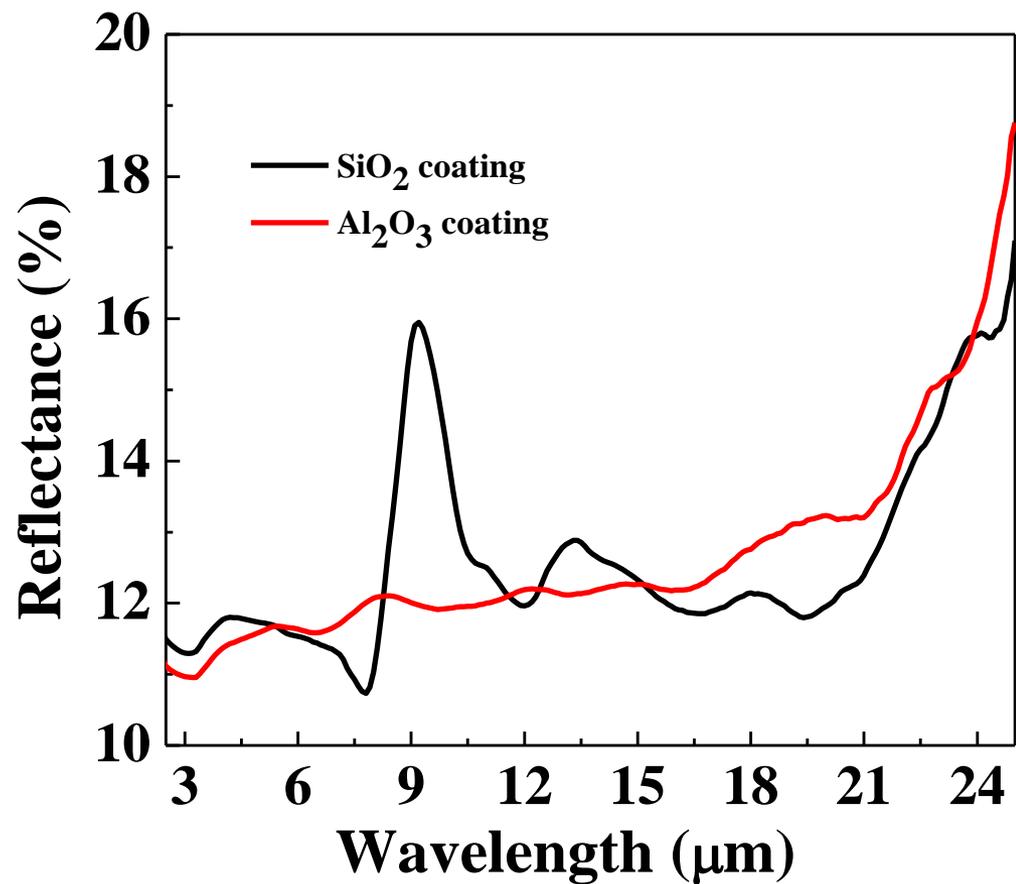


Fig. 6

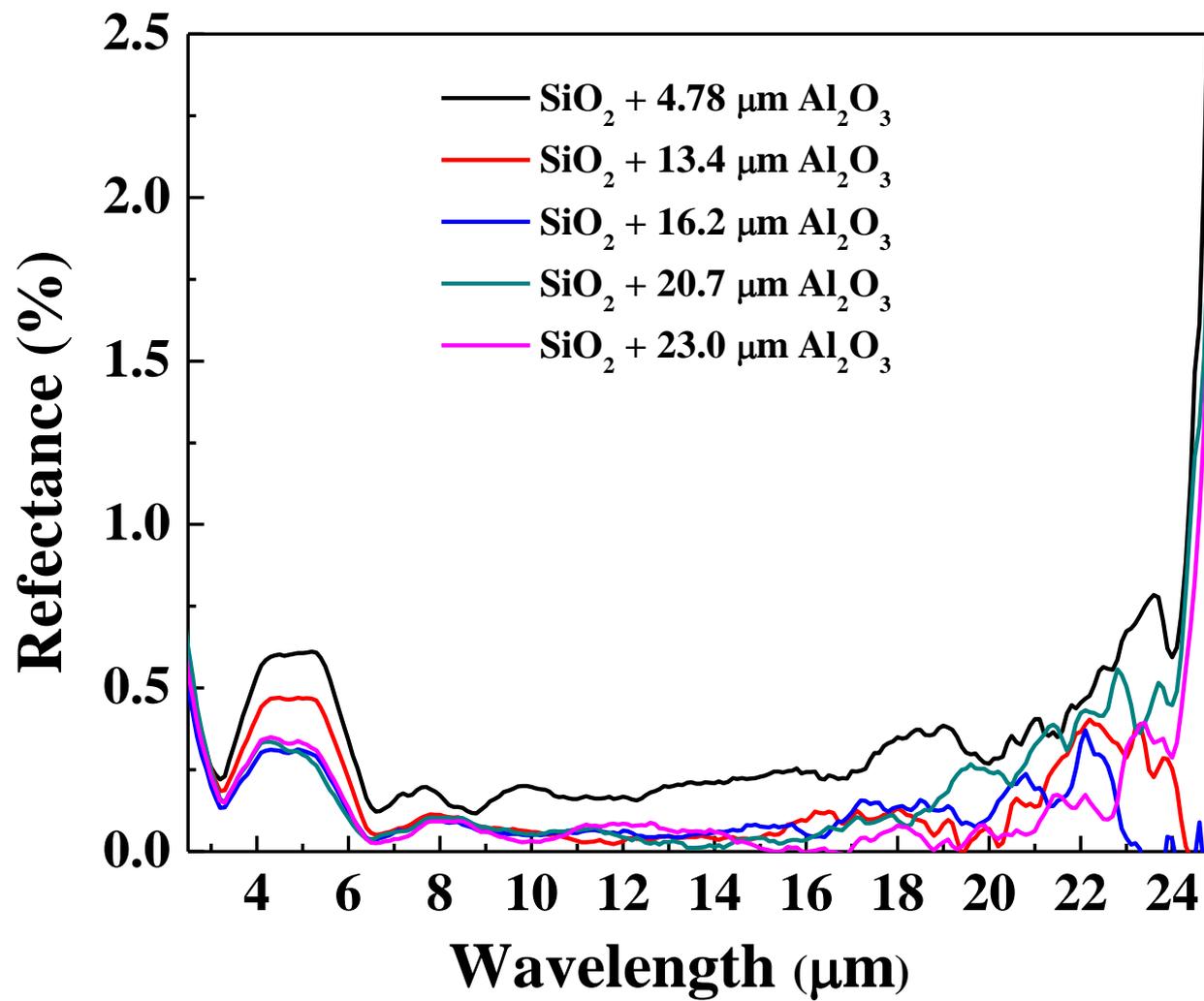
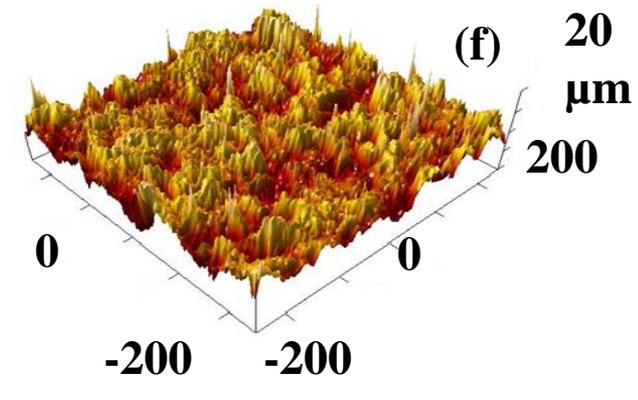
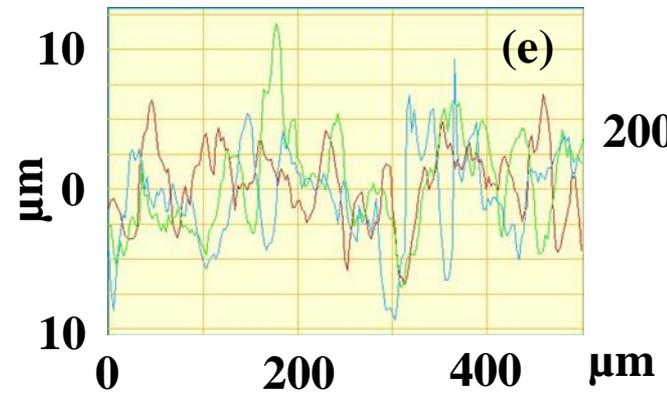
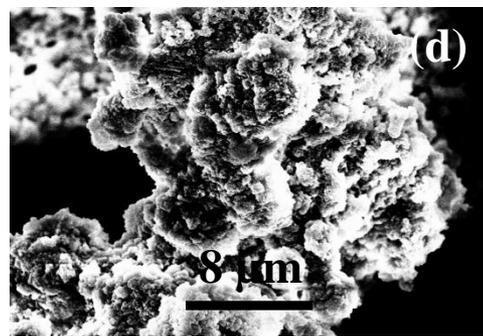
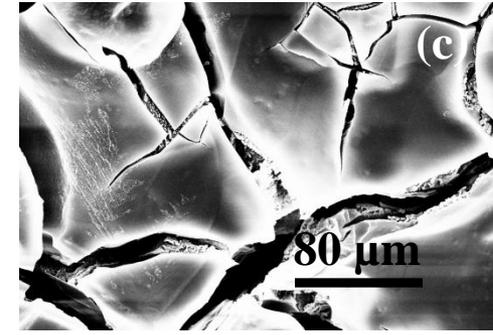
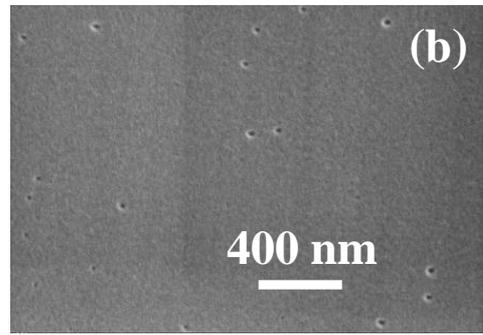
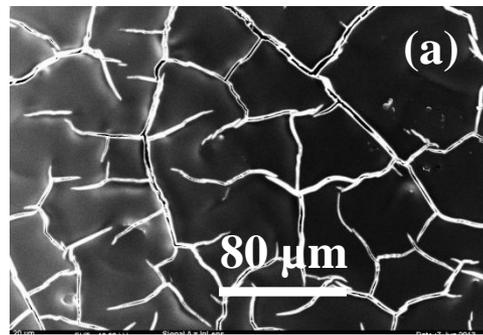


Fig. 7



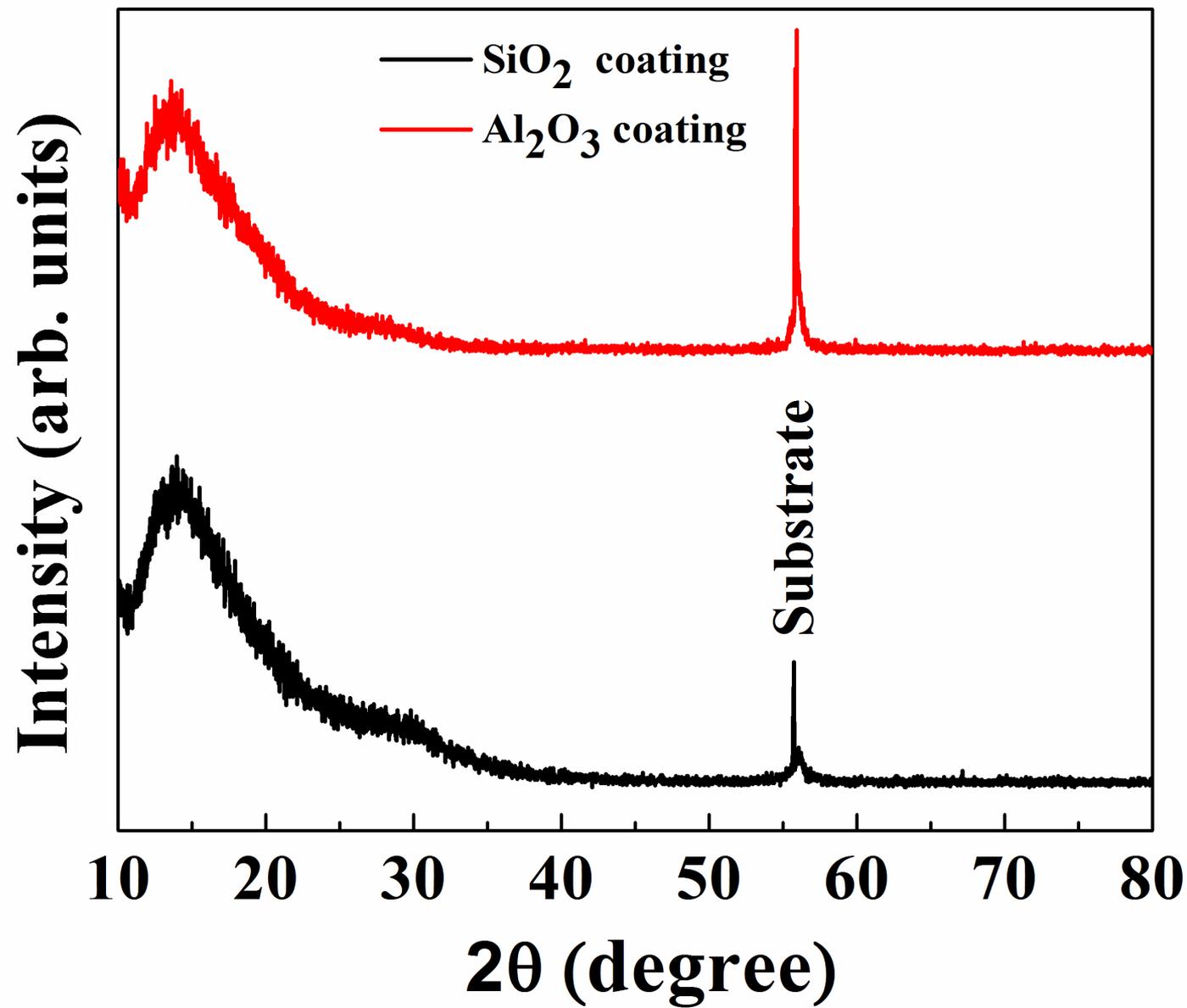


Fig. 9

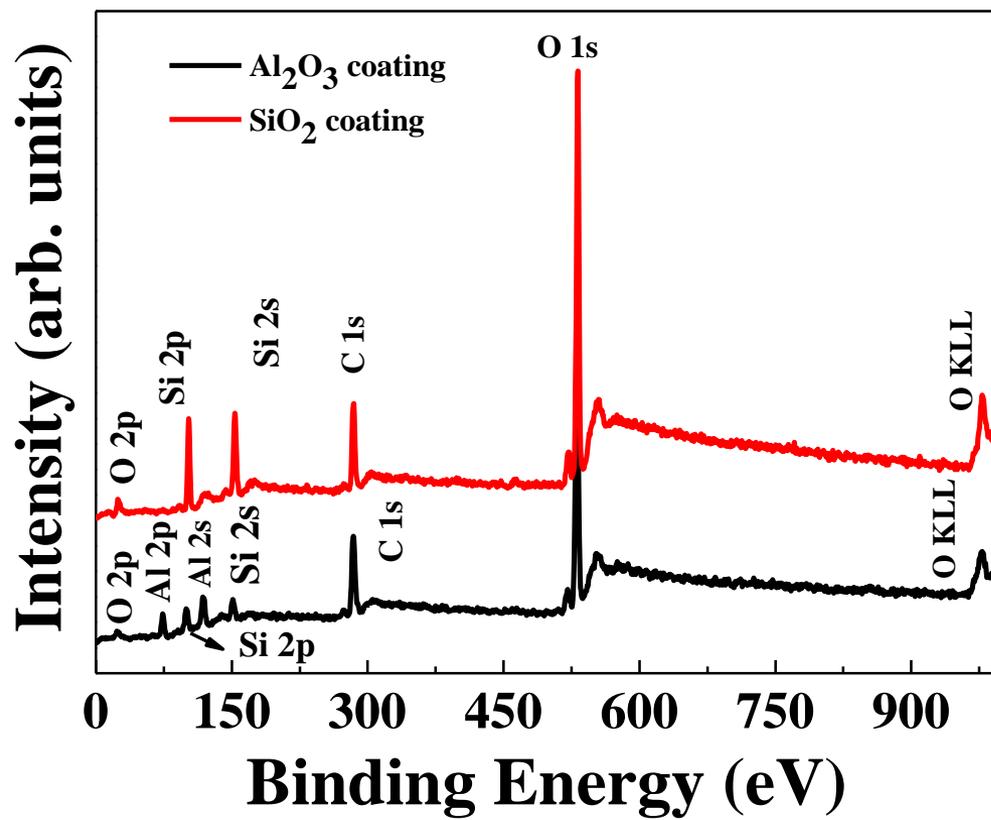


Fig. 10

