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Angular solar absorptance and thermal stability of Mo–SiO_2 double cermet solar selective absorber coating

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Abstract

In this paper, the angular solar absorptance of Mo–SiO_2 double cermet solar selective absorber coating was simulated based on the deduced optical constants and calculated from measured reflectance spectra in the wavelength range 0.25–2.5 μm for incidence angles between 0° and 75° by interval of 15°. It was found that Mo–SiO_2 double cermet solar selective absorber with angular absorptance $\alpha = 0.945$ from 0° up to 60° is a wide-angle absorptance coating. The effect of thermal annealing on optical properties, microstructure and morphology of Mo–SiO_2 double cermet solar selective coating was investigated. The annealing in vacuum at 600 °C results in grain refinement of Mo particle, denser cermet layer and photo-thermal conversion efficiency increasing of 0.6%. Annealing at 800 °C leads to grain growth of polycrystalline structure Mo, inter-diffusion in cermet layer and the photo-thermal conversion efficiency decreasing of 1.3%.

Keywords: Angular solar absorptance; Thermal stability; Mo–SiO_2; Solar selective coating

1. Introduction

The parabolic trough concentrated solar power is a promising commercialized solar thermal power technology, with its advantages of largest installed capacity and continuous power generation. The critical part of these systems is the solar selective absorber coating used to convert solar energy to thermal energy. There is an increasing demand for high temperature solar selective absorber coating (Kennedy and Price, 2005). The high temperature thermal stability is vital for selective absorber coating. Numerous materials and structures of solar selective absorber coatings have been developed (Selvakumar and Barshilia, 2012). In recent years, several high temperature solar absorber materials based on cermets and multilayer coatings: Mo–Al_2O_3 (Cheng et al., 2013), Ag–Al_2O_3 (Barshilia et al., 2011), AlNi–Al_2O_3 (Xue et al., 2013), Al_xO_y/Pt/Al_xO_y (Nuru et al., 2014a,b), MgO/Zr/MgO (Nuru et al., 2015), NbTiON/SiON (Liu et al., 2012), SS/TiAlN/TiAlSiN/Si_3N_4 (Feng et al., 2015), and Ti/AlTiN/AlTiON/AlTiO (Barshilia et al., 2014) have been reported by various authors. Another typical double cermet selective coating structure experimentally presented good performance of solar absorptance (Zhang and Mills, 1992; Zhang, 1999). Double cermet Mo–AlN sputtered on copper substrate

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was thermally stable in vacuum up to 500 °C (Zhang, 2000). Mo–SiO_2 double cermet absorber was fabricated and prepared for high temperature application (Esposito et al., 2009). All of these high temperature absorber coatings need to focus on thermal stability of the microstructure, morphology, interlayer diffusion and their mechanism under high temperature.

According to the solar thermal power application features of trough solar tracking, it is suitable for using single-axis tracking structure placed north and south (Ronnelid and Karlsson, 1997). Optical characterization of solar absorber is usually performed by measuring spectral reflectance at near normal angle of incidence. Since the incident angle of concentrating solar parabolic collector varies with geographical location and time (Helgesson et al., 2000), the solar absorptance is a function of the angle of the incident light on the absorber coatings. It is necessary for solar absorbers to have high absorptance at wide incident angle range. The angular absorptance of Ni–Al_2O_3 and sputtered Ni–NiO_x were theoretically calculated and measured (Tesfamichael and Wackelgard, 1999, 2000), it was found that double layer structure can enhance higher angle solar absorptance due to thin film interference effects. Wide-angle solar selective absorbers were designed by aperiodic Mo/TiO_2/MgF_2 and W/TiO_2/MgF_2 metal-dielectric stacks (Sergeant et al., 2009). W–SiO_2 and Ni–SiO_2 cermet-based solar selective absorbers with wide-angle absorptance were fabricated for high temperature applications (Sakurai et al., 2014). The angular solar absorptance of absorber coating is important for solar thermal application, but study in this aspect is rare.

In our previous work, the high performance double cermet solar selective absorber coatings were simulated by Macleod software (Zheng et al., 2013a). Mo–SiO_2 double cermet absorber was optimized based on the fitted optical constants and then prepared by magnetron co-sputtering (Zheng et al., 2013b). In this paper, we simulated reflectance spectra for different incident angles of prepared Mo–SiO_2 double cermet absorber based on the deduced optical constants from Zheng et al. (2013b), and then measured the reflectance data of experimental samples. The angular solar absorptance was calculated from reflectance spectra in the wavelength range 0.25–2.5 μm for incidence angles between 0° and 75° by interval of 15°. Mo–SiO_2 double cermet absorbers were annealed at 600 °C, 800 °C in vacuum for 6 h and characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM), UV–vis spectrophotometer and Fourier Transform Infrared Spectrometer. The effect of thermal annealing on microstructure, morphology, optical properties and thermal stability of Mo–SiO_2 double cermet absorbers were presented.

2. Experimental details

Mo–SiO_2 double cermet coatings were prepared by magnetron co-sputtering on polished stainless steel sheets and single crystal silicon for annealing. The experimental details had been described in Zheng et al. (2013b). The reflectance spectra for different incident angles were simulated by Macleod software based on the deduced optical constants in Zheng et al. (2013b). In order to reduce the scattered reflection, Mo–SiO_2 double cermet coatings sputtered on Schott BK7 optical glass were used to measure the reflectance for different incidence angles between 0° and 75° with Perkin–Elmer Lambda 750 integrating sphere spectrometer. The coating surface was assumed to be smooth and the effects of surface roughness on scatter were not considered.

To study the thermal stability of the coatings, they were annealed in a furnace in vacuum (3×10^{-2} Pa) at 600 °C, 800 °C for 6 h, the accuracy of the set temperature was ±1 °C. The temperature was increasing from room temperature to desired temperature at a rate of 10 °C/ min and then followed by furnace cooling. The X'Pert Pro MPD XRD instrument with Cu Kα radiation was used for XRD measurement. A Perkin–Elmer S2000 Fourier Transform Infrared Spectrometer was used to measure the normal reflectance between 2.5 and 20 μm. The Hitachi S-4800 Field Emission SEM was used to acquire the cross-section morphology of the as-deposited and annealed coatings.

3. Results and discussions

3.1. Angular solar absorptance

In order to obtain data of angular solar absorptance, the reflectance spectra for different incident angles were simulated based on the deduced optical constants, and the reflectance data of experimental samples were measured. Fig. 1 presents simulated reflectance spectral of Mo–SiO_2 double cermet absorber at different incident

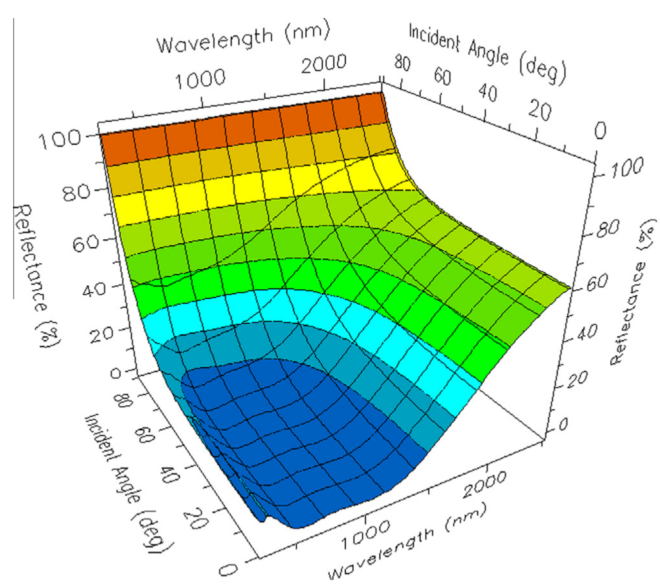

Fig. 1. Simulated reflectance spectra of Mo–SiO_2 double cermet absorber coating at different incident angles from 0° to 90°.