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Review Paper on Selective Coating of Absorber Tube for Parabolic Trough Collector

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Abstract

This paper describes the various coatings used for absorber tube of Parabolic Trough Collector (PTC) and their properties. Solar thermal selective absorber coatings are currently characterized by their solar absorptance and their thermal emittance. Mostly coating is by electroplating, paint coatings and deposited cermet. This paper mainly focus on properties of Black chrome, Black Nickel , Black cobalt, Black-colored CuFeMnO4 spinel powder, Thickness-sensitive spectrally selective (TSSS) paint coating, spray-coated graphitic films and there manufacturing process. The coatings need to be stable in air in case the vacuum is breached. Current coatings do not have the stability and performance desired for moving to higher operating temperatures.

Keywords: Absorptance , Emittance, Coating.

Introduction

The use of selective coatings has been widely established as an industrial application which used to absorb solar thermal energy. Demands for design and construction of solar absorber plates to achieve reduced energy consumption and its applications in the areas of electrical energy, heating and cooling systems lead to the development of growing of selective coatings. Concentrating solar systems use solar absorbers to convert sunlight to thermal power. To increase the operating temperature of the solar field approximately 400°C to 500°C , efficient selective coatings are needed that have both high solar absorptance and low thermal emittance at 500°C. The coatings need to be stable in air in case the vacuum is breached. Current coatings to not have the stability and performance desired for moving to higher operating temperatures. For efficient thermal conversion solar absorber surfaces must have high solar absorptance (α) and a low thermal emittance (ε) at the operational temperature. For parabolic trough applications, the ideal spectrally selective surface would be low-cost and easy to manufacture, chemically and thermally stable in air at elevated temperatures ($T \geq 500$ºC), and have a solar absorptance ≥ 0.98 and a thermal emittance ≤ 0.05 at 500ºC.

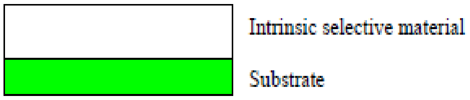
The applications and requirements for thin film coatings in solar-thermal power systems are reviewed. The substantial impact of selective absorber coatings and antireflection coatings on both flat plate and concentrating type solar collectors is covered. The results of durability life tests on a high-temperature stable, an efficient way to reduce thermal losses from the absorber is by using selective absorber coatings. An ideal coating is one that is a perfect absorber of solar radiation while being a perfect eflector of thermal radiation. Such coating will make a surface, a poor emitter of thermal radiation. Hence a selective coating increases the temperature of an absorbing surface.A selective surface is a surface that has a high absorptance for short wave radiation and a low emittance of long wave radiation.

Properties of Coatings.

1. Absorptance for the solar spectrum must be high.
2. Emissivity must be low.
3. Spectral transition between the region of high absorptance and low emittance should be as sharp as possible.

4. The optical and physical properties of the coating must remain stable under long term operation at elevated temperature,repeated thermal cycling ,air exposure,ultraviolet radiations .
5. Adherance of the coating to the substrate must be good.
6. Coatings should be easily applied to collectors of desired size and shape.
7. Coatings must be economical.
8. It should be able to withstand atmospheric corrosion and oxidation

Schematic designs coatings.



a) Intrinsic absorber

b) Semiconductor-metal tandems

c) Multilayer absorbers

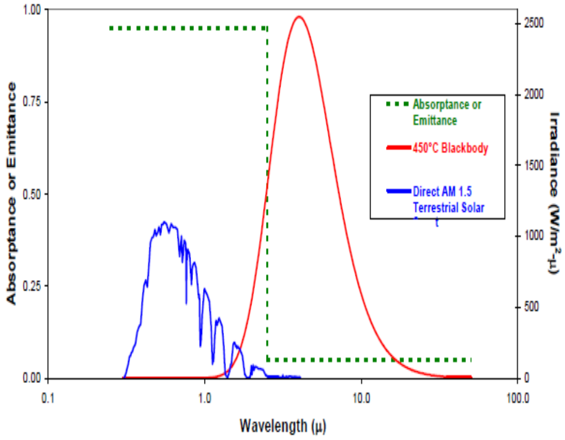


Figure 1. Spectral performance of an ideal selective solar absorber.

Black chrome (Cr-Cr_2O_3), has an Absorptance & Emittance at (100°C) is 0.97/0.09 for temperatures. Black chrome is commercially produced by MTI on Ni-plated Cu in the United States. Researchers have found that a layer of Ni between the substrate and black chrome coating gives better stability up to 400°C. Oxidation of the metallic Cr crystallite and densification of the crystallites primarily cause the degradation of the selective coating. At high temperatures, Ni diffusion from the substrate contributes to optical degradation. When the Cr^{+3} concentration in the standard black-chrome baths was reduced, laboratory samples were produced that are stable in air for 3908 h at 350°C and for 670 h at 400°C. The reflectance after exposure at 350°C in air is approximately equivalent to that after exposure at 400°C in vacuum. Heat treatments established that black chrome failed optically between 500º-600°C after 1 h in both air and vacuum and the coating failed mechanically by peeling after 600°C in air. Black chrome solar selective films can be modified by admixing molybdenum, up to 20% of the chromium content. Absorptance is stable for an Mo/Cr ratio of 0.6% at a value of 0.95 for 146 h up to 425°C in air

Black Nickel (NiS-ZnS) is formed by the electrodeposition of nickel on a metal substrate in the presence of zinc and sulfides. Different groups have modified the electrodeposition bath and process to produce coatings where Absorptance & Emittance at (100°C) is 0.88-0.96/0.03-0.10. Black nickel degrades in humid environments and on exposure to temperatures of 200°C and is therefore not applicable for PTC applications. Nearly all other black nickel solar-selective coatings contain oxides of nickel. Its high solar-absorbing characteristics, $\alpha/\varepsilon(100°C)=0.92\text{-}0.98/0.08\text{-}0.25$ with a thermal stability up to 300°C, are a result of the micro-surface light-trapping morphology. This coating is produced by combining two processes. the electrodeposition of the crystallographic metallic alloy and applying a sol-gel overcoat.

Black cobalt coatings on bright nickel plated on brass and copper substrate were prepared by the electrodeposition method. The influence of heat treatment on optical absorption and surface morphology of black cobalt films deposited on brass substrates has been studied. Heat treatment of black cobalt films deposited on brass substrates caused cracks in the surface structure. Heat treatment of black cobalt deposited on brass caused a slight decrease in an absorption in the near-IR region. Due to high absorption in visible region the best substrate for a black cobalt solar absorber coating is bright nickel-plated on copper substrate.

Thickness-sensitive spectrally selective (TSSS) paint coatings are low-temperature alternatives for selective coatings. Paint coatings called Solariselect are spectrally sensitive Absorptance & Emittance at (100°C) =0.92/0.38 when applied 2-3 µm thick to aluminum substrates. Various black paints suitable for coil coating applications on aluminum with different pigment-to-volume concentration (PVC) ratios (27%-39%) were made from phenoxy resin and FeMnCuOx pigment. Optimization of the optical properties [α/ε(100°C)=>0.92/<0.015] of the TSSS paint coating was obtained by adding fumed silica and a silane coupling agent in a PVC ratio of about 35% . The paint is stable up to 135°C, but the paint thins and begins to outgas at 220°C . Different (more expensive) paint formulations may improve the paint stability. Without substantial improvements in the paint stability, the TSSS paint coatings will not be applicable for concentrating applications.

Black-colored CuFeMnO4 spinel powders and films were prepared using the sol-gel process from Mn-acetate and Fe- and Cu-chloride precursors. For CuFeMnO4/silica films, 3-aminopropyl-triethoxysilane (3-APTES) and tetraethoxysilane (TEOS) were used in 1:1 molar (Mn:Cu:Fe):silica proportion. The films were deposited by dip-coating and thermally cured at 500°C. The resulting (Mn:Cu:Fe)/3-APTES coatings had a composite structure consisting of the Cu1.4Mn1.64 spinel and the amorphous SiO2 lower layer [91]. The Fe concentration varied from lower (Mn:Fe=2.6:1) to higher Mn/Fe ratios composition (Mn:Fe =1.5:1). The composition of the upper grains corresponds to the nearly stoichiometric ratio of 3:3:1 of the (Mn:Cu:Fe) precursors. The corresponding composite films had Absorptance & Emittance (100°C) =~0.6/~0.29-0.39, where the α is too low and the ε is too high. This is caused by differences in the film thickness. The absorbing layer of the spinel film (200 nm) was much thinner than the lower amorphous SiO2 layer (800 nm). Using TEOS and a different base catalyst (NH3)aq increased the α (>0.93), but the thermal emittance values were too high because of the presence of large SiO2 spherical particles (400-420 nm) [91]. These films are not suitable as a solar-selective coating, but replacing the highly emitting SiO2 with an IR-transmitting (i.e. non-emitting) ZrO2, TiO2, or CeO2 layer should improve the performance of the absorbers and could make them suitable for CSP Selective coatings can be made with thick **spray-coated graphitic films** with Absorptance α=0.80-0.90 and Emittance ε =0.5-0.6 as diamond-like carbon (DLC), a glassy carbon, or as bulk graphite. A durable amorphous hydrogenated carbon (a-C:H)/Cr on copper substrate has been manufactured on an industrial scale by medium-frequency (MF)pulsed plasma technology with a α/ε(100°C)=0.92/0.025 and has passed the IEA Task X performance criterion for low-temperature applications. Optical selective surfaces with tungsten-, chromium-, and titanium-containing a-C:H films on aluminum substrates have been produced by combining PVD and plasma-enhanced chemical vapor deposition (PECVD) [97,98]. Even though the layer thickness and stoichiometry has not been optimized, experimental results are promising, with a α/ε(100°C)=0.876/0.061. Accelerated aging studies at 220°C and 250°C in air pass the performance criterion, and the service lifetime is predicted to be more than 25 years for flat-plate collectors; however, the temperature stability of this material is too low for it to be applicable for CSP applications.

Conclusion

Many selective surfaces capable of operating at temperatures greater than 400°C have been developed and are cited in the literature. Ni-pigmented Al_2O_3, graded Ni-NiO_X, black graded Mo or W-Al_2O_3, and double SS-AlN cermets are commercially available, but most do not fulfill the requirements of the PTC. For parabolic trough applications, the spectrally selective surface should be stable to 500ºC, preferably in air, have a solar absorptance of 0.950-0.98 and a thermal emittance of 0.1 at 400°C. The most promising candidate(s) should be made and tested. The capability should be built to allow spectrally selective coatings to be exposed and measured at their operating temperatures and conditions for longer periods of time to determine the durability and thermal stability of the materials. In addition, a criterion needs to be developed for high-temperature selective surfaces applicable for concentrating applications.

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