SAND2013-7781P

Selective Solar Coatings for Concentrating Solar Power Applications

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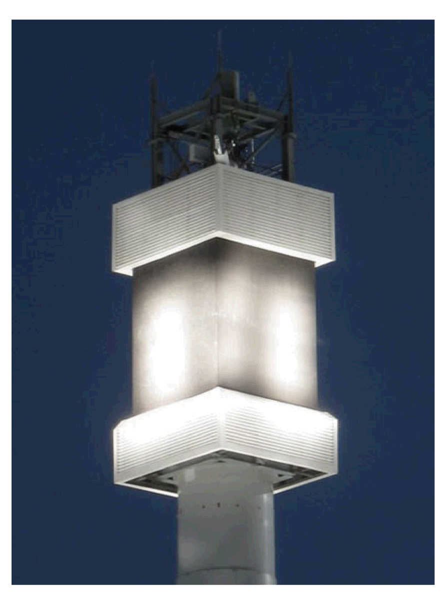
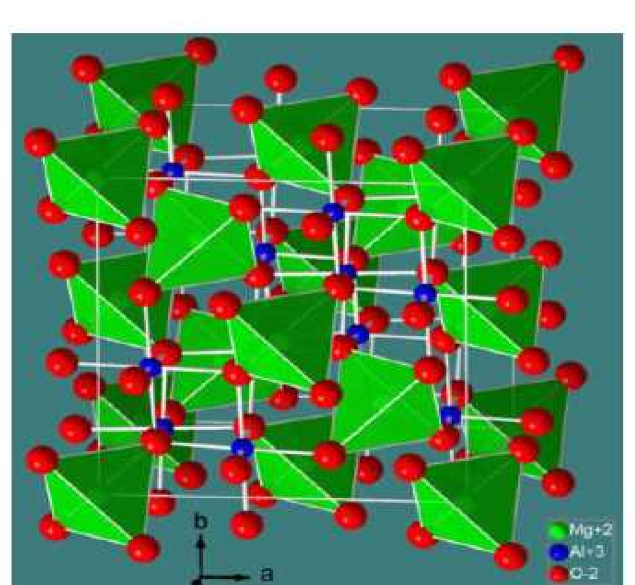
Abstract

Concentrating solar power (CSP) systems use concentrated sunlight to heat a working fluid that is used to generate electric power. Solar selective absorbers are used to coat the tubes exposed to sunlight in order to maximize the amount of solar radiation absorbed in the form of heat. Higher operating temperatures (> 600 ° C) for CSP towers are necessary to achieve higher power cycle efficiencies, as well as lower thermal energy storage costs. One of the major issues with increased receiver temperatures is the increase in thermal energy radiated from the absorber. Energy losses in this way can be significant, approximately 7% annually at the desired temperatures. This can be ameliorated by the use of a more efficient selective absorber coating. A selective absorber should have a high absorptance (α > 0.95) in the solar spectrum and a low thermal emittance (ε < 0.4) in the infrared spectrum. Lower emissivity allows higher operating temperatures to be achieved without higher thermal losses. The coating must be robust enough to survive many heating cycles in air and still maintain its selective properties. When applied, these coatings will increase the overall sustainability and cost effectiveness of the CSP tower. The goal of this study is to find materials that function better than the current industry standard, Pyromark™ 2500.



Concentrating solar power tower uses a field of mirrors (heliostats) to reflect the sunlight onto a central receiver. The energy absorbed is then used to heat a working fluid and in turn generate steam to power a turbine generator.

Introduction



The spinel structure.

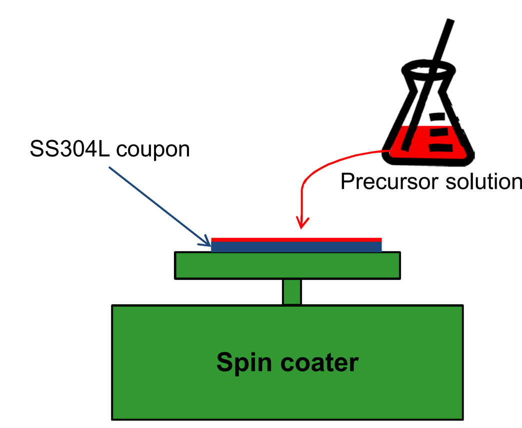
Metal oxide spinels with the composition AB_2O_4 were chosen as target materials for solution-based deposition methods because of their inherent high temperature and oxidation stability. Cobalt-based metal oxides (Co_3O_4) have shown promise as selective absorber materials and were chosen as a base for this study.

By doping the cobalt spinels with other transition metals, the optical properties of the composition can be altered, ideally to have a low thermal emittance while maintaining a high solar absorptance. These properties are primarily determined by the electronic properties of the crystal structure. Doping with transition metal cations allows for manipulation of the band structure of the material, creating the absorption selectivity.

Methods

Spin Coating Approach

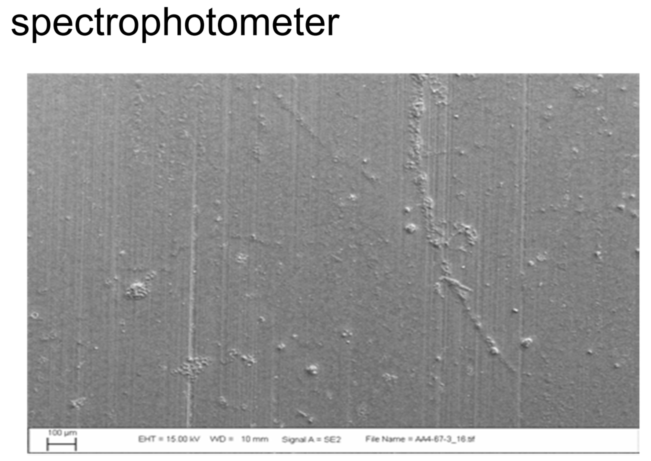
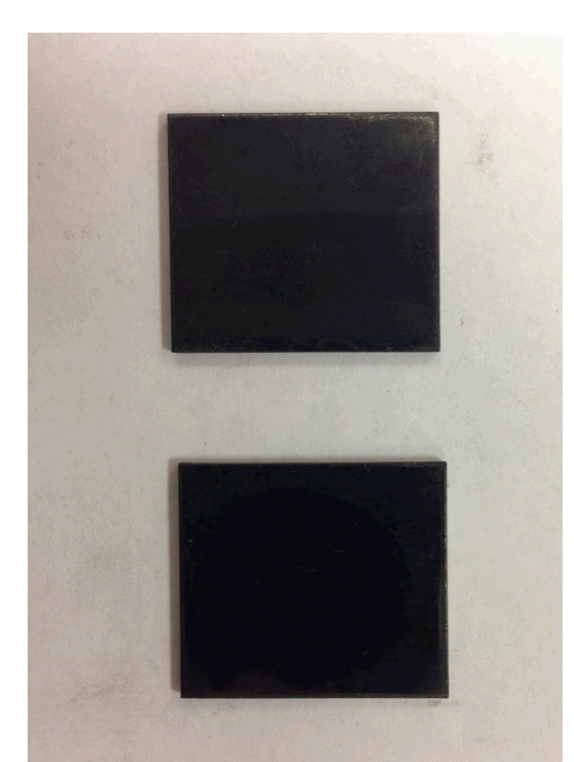
- Provides a facile and inexpensive method of coating stainless steel coupons
- Easily screened for stability and optical properties
- Solution was deposited onto a coupon, spun at 5000 rpm for 30 seconds, and dried on a hot plate
- After 10 layers, coupon was sintered in a box furnace at 600 °C
- Process was repeated to form coatings of 40-50 total layers



The spin coater is used to produce a thin layer of solution with each spin. The stainless steel coupon is held to the spinning shaft using a vacuum pump.

Measurement and Analysis

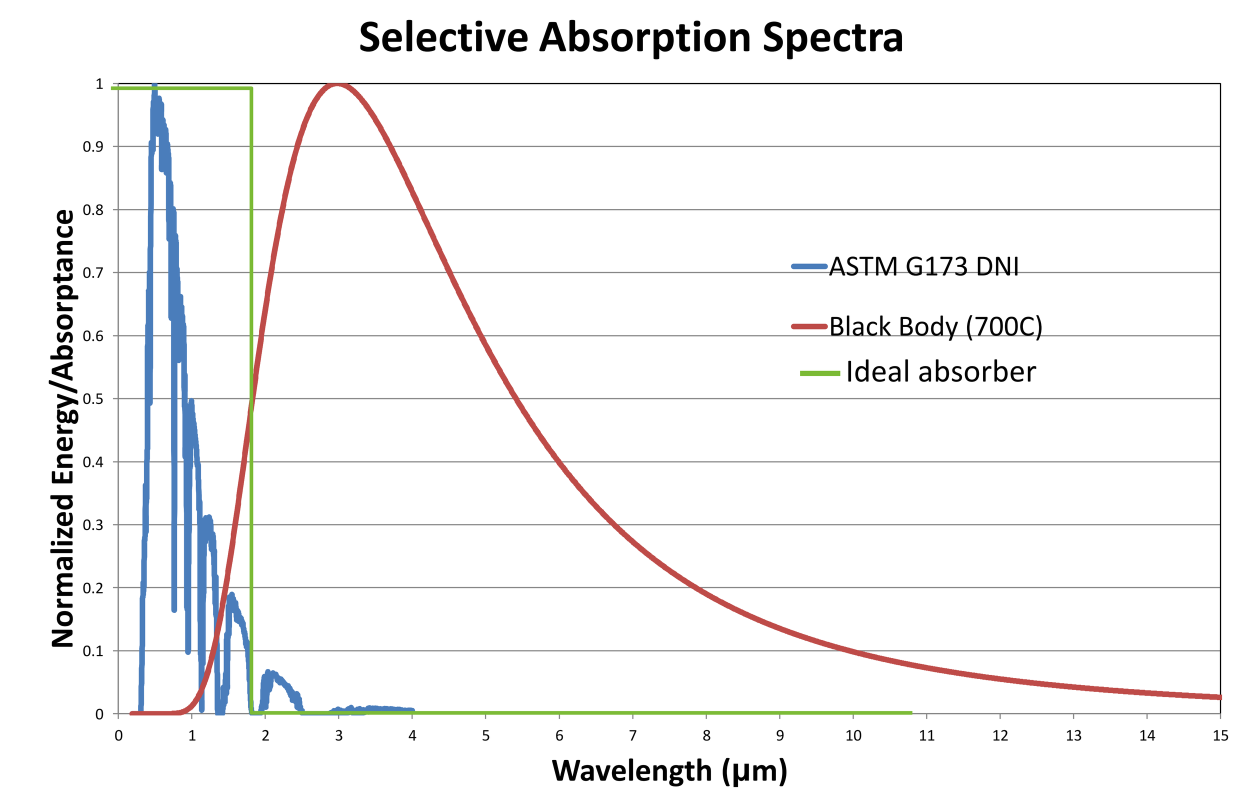
- Absorptance (α) measurements taken using a 410 solar reflectometer from Surface Optics Corporation and a solar spectrum reflectometer from Devices & Services Co.
- Emittance (ε) measurements taken using a ET100 emissometer from Surface Optics Corporation as well as a Temp 2000A from AZ Technology
- Diffuse reflectance performed using a Shimadzu UV 3600 UV-Vis-NIR spectrophotometer

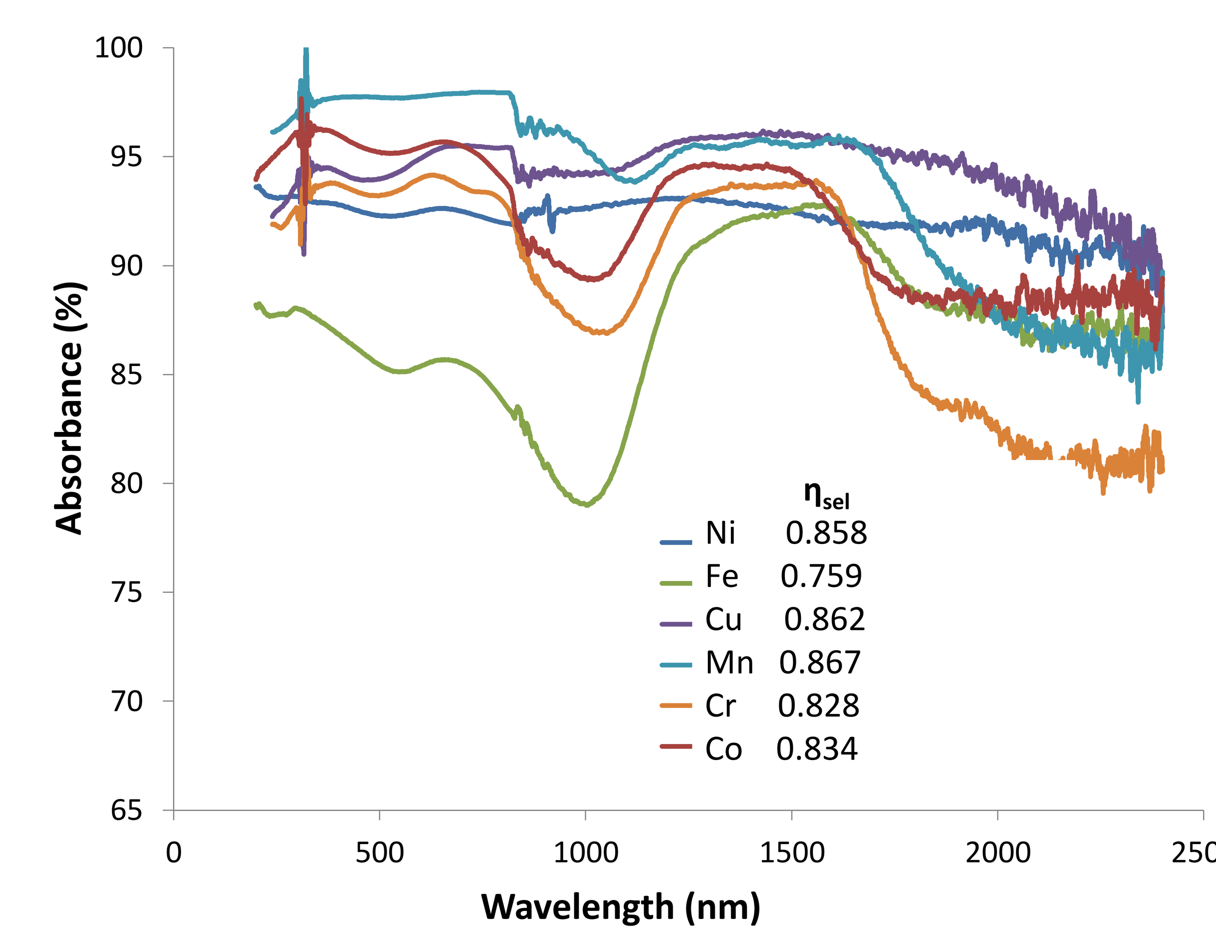
(Above) *: SEM image of the surface of a metal oxide spinel selective coating.* ***(Right)*** *two coupons coated with a metal oxide spinel.*

Results

Three transition metal series have been evaluated so far, copper, manganese and chromium. Each material was made in different dopant concentrations, ranging from ACo_2O_4, where A is the metal, to $A_{0.2}Co_{2.8}O_4$ in increments of 0.2. Pure Co_3O_4 and Pyromark™, the current industry standard, were also studied as benchmarks. In general, the higher concentration transition metal materials had the better selective properties. So far, $MnCo_2O_4$ has shown the most promise, it has one of the highest absorptance values as well as the lowest emittance value.



Ideal reflectance spectrum for a selective coating.



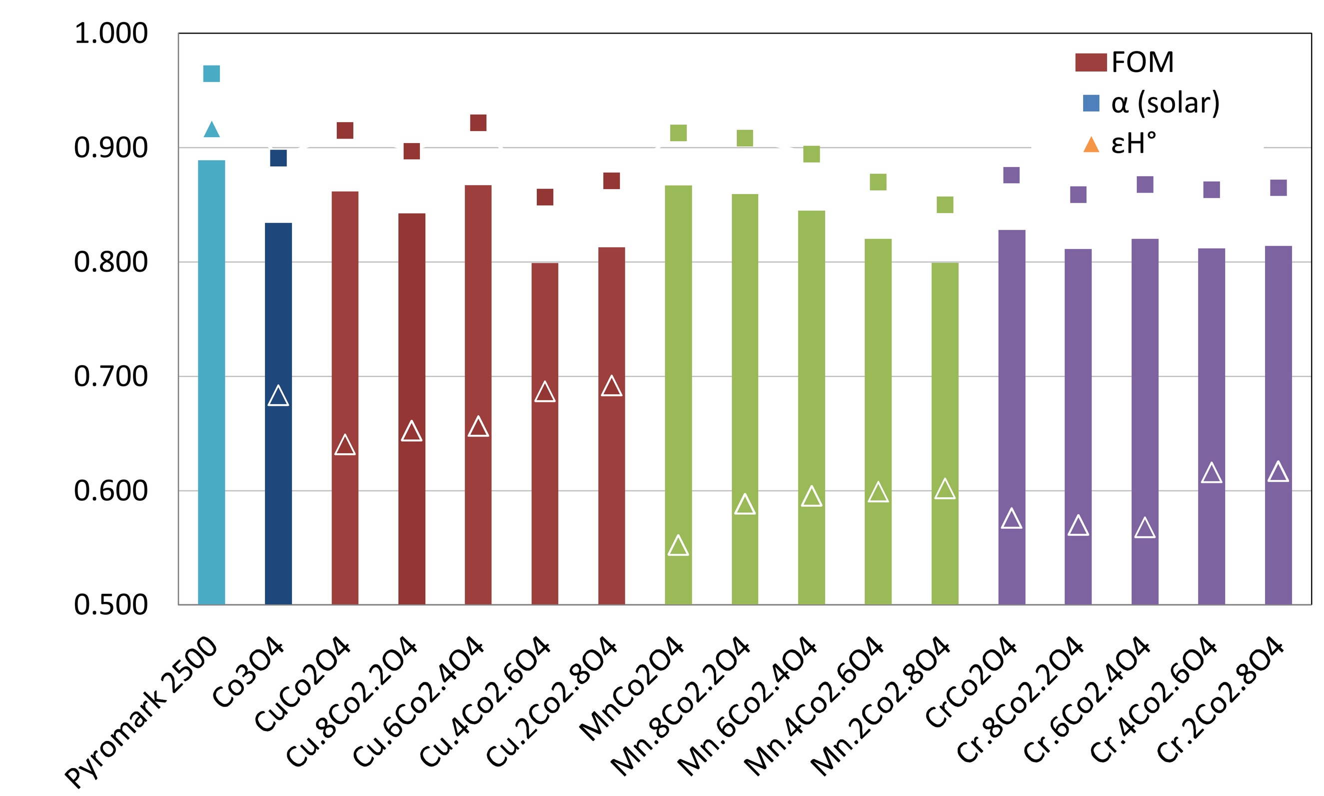
Diffuse reflectance of spin coated films, showing absorbance from 200 -2400 nm.

Figure of Merit, η_{sel}

$$\eta_{sel} = \frac{\alpha_s Q - \varepsilon \sigma T^4}{Q}$$

- α_s = solar absorptance
- Q = irradiance on the receiver (W/m^2)
- ε = thermal emittance
- σ = Stefan-Boltzmann constant ($5.67 \times 10^{-8}\ W/m^2/K^4$)
- T = surface temperature (K)

A figure of merit, η_{sel}, was developed to gauge the properties of the material and it is a combination of the absorptance and emittance values. The figure of merit takes into account the absorptivity and emissivity of the material, as well as operating temperature and solar flux. The data for each material can be seen in Figures (x-z) below.



The absorptivity, emissivity and figure of merit for each of the materials are shown here. Absorptivity is indicated by the square, emissivity is shown by the triangle, the figure of merit is designated by the bar. Each different Transition metal series is the same color.

Summary

- $MnCo_2O_4$ shows most promise out of materials tested
- Manganese doped materials showed lowest emissivities
- Copper doped materials showed highest absorptivities
- Chromium-doped materials generally showed lower FOM when compared to copper and manganese

Future Work

- Structural characterization of materials using SEM and XRD
- High temperature durability tests (600-800° C)
- On sun tests at National Solar Thermal Test Facility
- Testing of different transition metal series as well as combinations of multiple transition metals

Acknowledgements

This project was funded through DOE SunShot program.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.