ESI: Selective Solar Coatings for Concentrating Solar Power Applications

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Andrew Hunt, New Mexico Institute of Mining and Technology
Andrea Ambrosini, Cheryl Ghanbari, Sandia National Laboratories

Sandia National Laboratories

Abstract

Concentrating solar power (CSP) systems use concentrated sunlight to heat an absorber and create electric power. Higher operating temperatures 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 negated by the use of a selective absorber coating. A selective absorber has a high absorptance (>0.95) in the solar spectrum and a low thermal emittance (<0.4) in the infrared spectrum. The decreased emissivity of the absorber allows higher operating temperatures to be achieved without higher thermal losses. The coating must be robust enough to survive many heating cycles 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 test different materials to determine if they can function as a solar selective absorber.

Figure 1: Concentrated solar power tower use a field of mirrors (heliostats) to reflect the sunlight onto a central absorber. The energy absorbed is then used to heat a working fluid to power a turbine generator.

Introduction

For this application, 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 containing metal oxides 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 substance can be tailored 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 2000 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

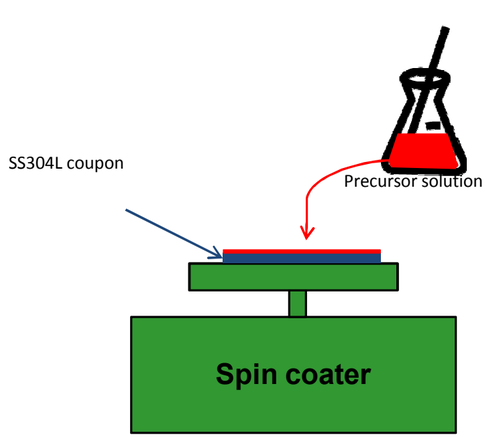
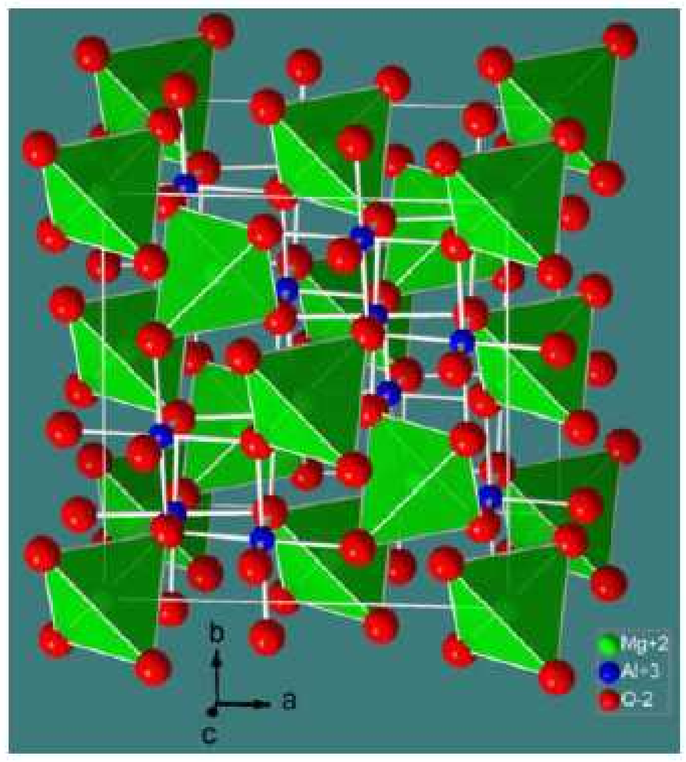


Figure 2: The spin coater is used to produce a thin layer of solution with each spin. The stainless steel coupon is held to the spinning shaft using a vacuum pump.

Measurement and Analysis

- Absorptance measurements taken using a 410 solar reflectometer from Surface Optics Corporation and a solar spectrum reflectometer from Devices & Services Co.
- Emittance 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 3600 UV-Vis_NIR spectrophotometer



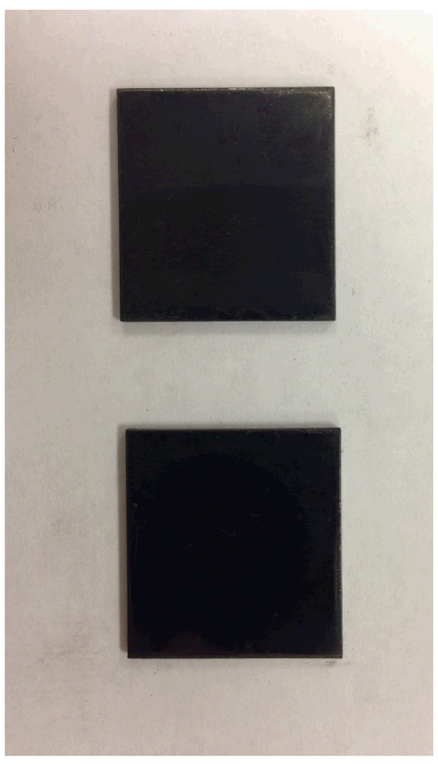


Figure 3: The spinel structure is illustrated on the left. On the right are two coupons coated with a metal oxide spinel.

Slide 1

aa9 Too many words throughout poster. Be concise; use bullets where appropriate
Andrea Ambrosini, 7/26/2013

aa20 Actually, you are heating a working fluid that creates steam to run a turbine. The absorber is what coats the tubes contaiing the fluid in order to absorb as much heat as possible from the solar radiation.
Andrea Ambrosini, 7/26/2013

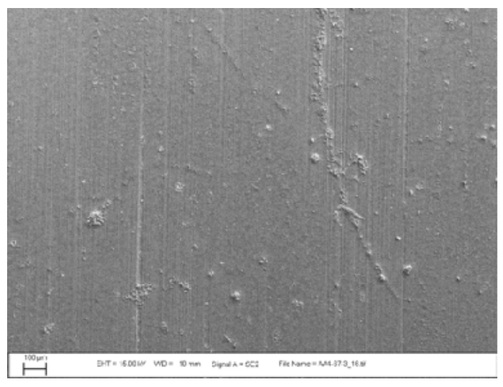


Figure 4: SEM image of the surface of a metal oxide spinel selective coating.

Results

Two transition metal series have been evaluated so far, copper and manganese. Each material was made in different dopant concentrations, ranging from ACo_2O_4, where A is the metal, to $A_{.2}Co_{2.8}O_4$ in increments of 0.2. In general, the higher concentration transition metal materials had the better selective properties compared to the baseline Co_3O_4. The copper doped materials have the higher absorptances, while the manganese doped materials maintain lower emittance values. A figure of merit was developed to gauge the properties of the material and it is a combination of the absorptance and emittance values. The individual data for each material can be seen in the figures below.

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

- α_s = solar absorptance
- Q = irradiance on the receiver (W/m^2)
- ε = thermal emittance
- σ = Stefan-Boltzmann constant ($5.67x10^{-8}$ $W/m^2/K^4$
- T = surface temperature (K)

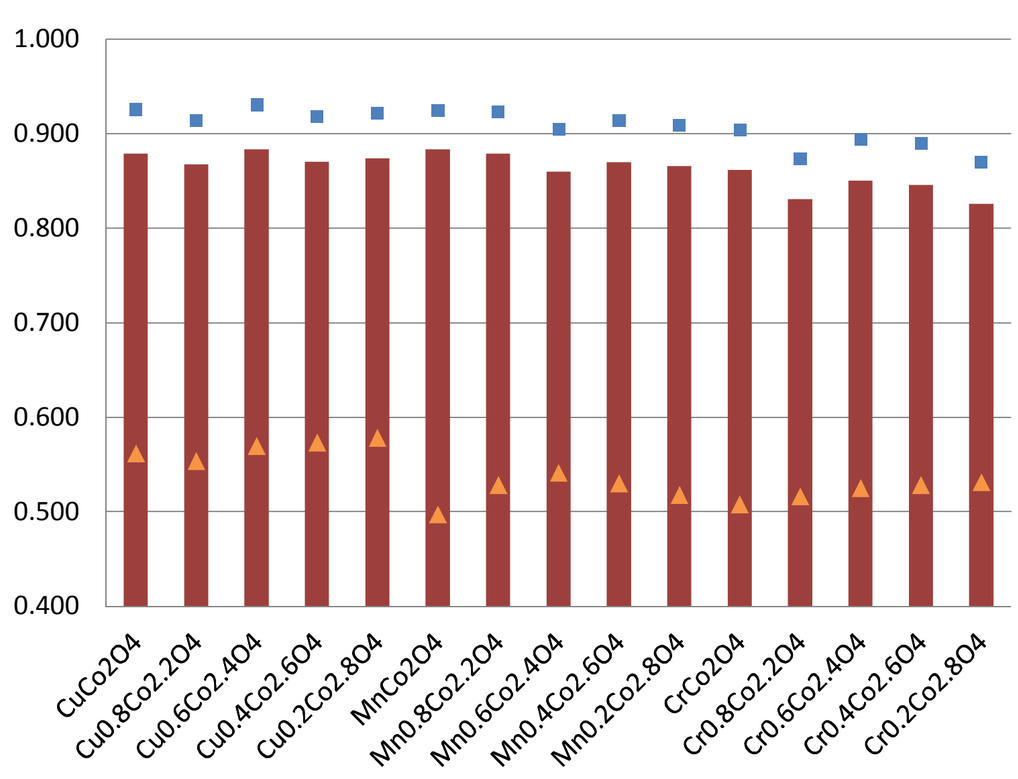


Figure 5: This graph depicts the absorptivity, emissivity, and figure of merit for each of the materials. The absorptivity is indicated by the green square, the emissivity is shown by the orange triangle, and the figure of merit is shown as the red bar.

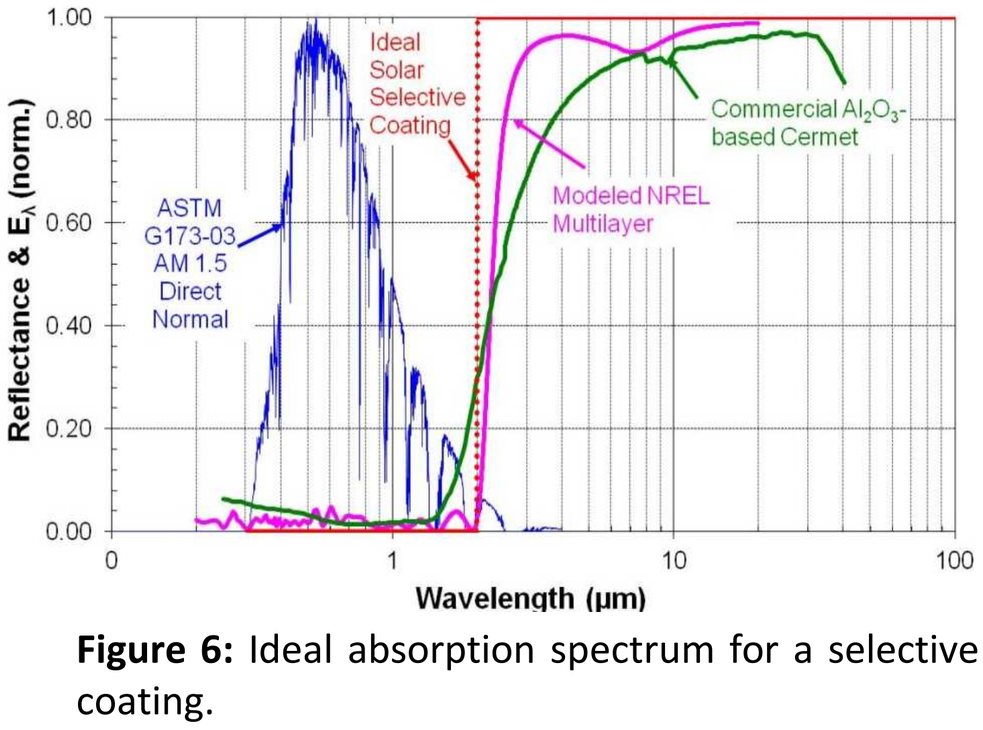
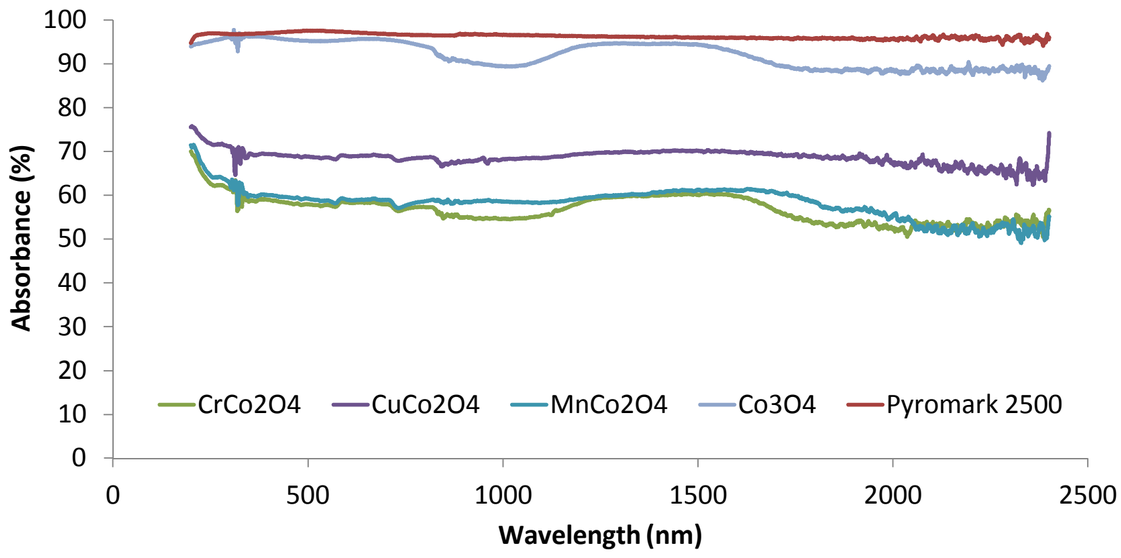


Figure 6: Ideal absorption spectrum for a selective coating.



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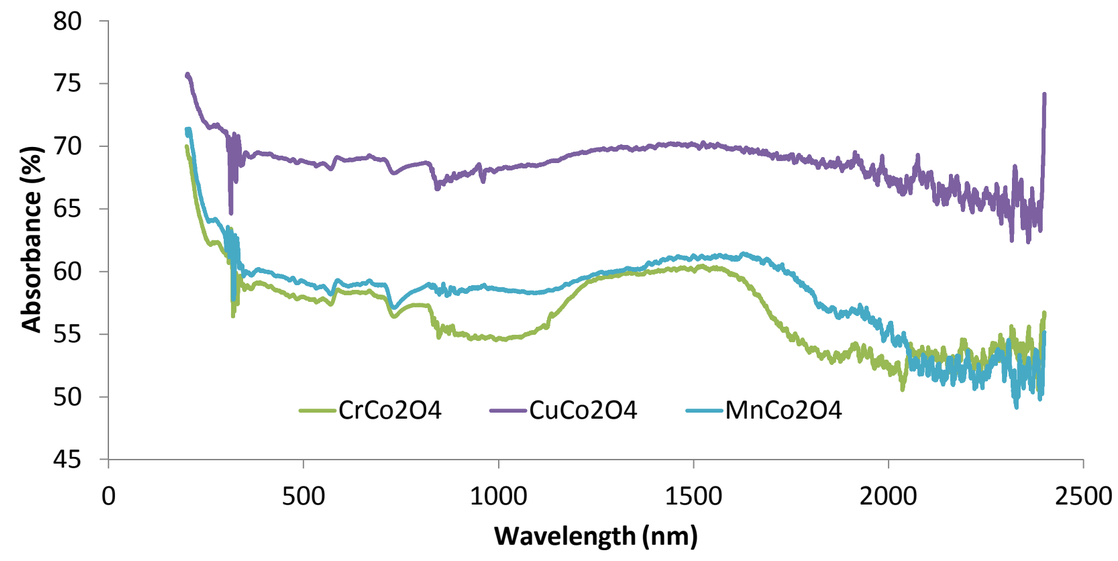

Figure 7: Here is a scan from a UV-Vis spectrophotometer. The spectrophotometer measures the amount of light absorbed or reflected at different wavelengths. For our purposes, an ideal substance would have a much larger dip in absorptance at the higher wavelengths.

Summary and Future Work

Future work is planned to test other materials as well. Samples containing chromium have already been synthesized but have not been fully analyzed yet. Analysis of other transition metals and combinations of different transition metals will yield more possibilities and hopefully better options for a selective coating.

Energy Surety

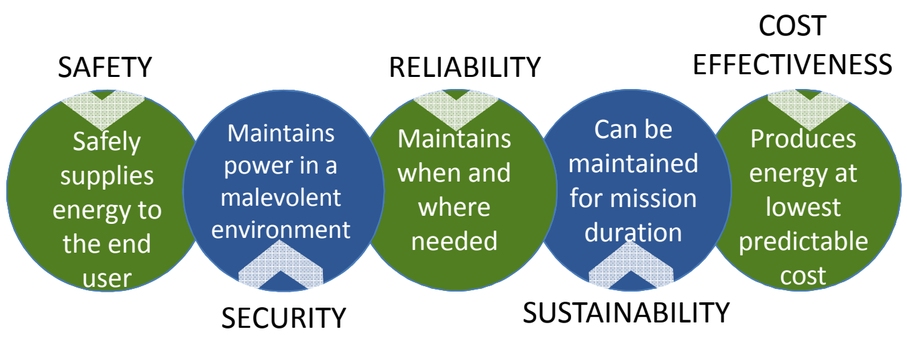

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Figure 8: The five principles of energy surety.

Solar selective coatings apply to three of the facets of the energy surety program. With selective coatings, CSP towers will be able to operate in a more efficient and cost effective manner. They will also ideally increase both the reliability and sustainability of the installations.

Acknowledgements

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Pictures:
emeraldinsight.com/journals.htm?articleid=876772&show=html
www.aee-li.org

Degree Pursuing: Bachelors of Science
Major: Chemical Engineering
Expected Graduation Date: Spring 2016
Manager: Subhash Shinde
Organization: Concentrating Solar Power/6123

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U.S. DEPARTMENT OF ENERGY
National Nuclear Security Administration
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Slide 2

aa16 specify UV-Vis spectrophotomer. This might be a ore effective graph if you overlayed several amples and added pyromark as a reference. I would plase the ideal spectrum (Fig 6) first and explain that.
Andrea Ambrosini, 7/26/2013

aa17 Here is where you should put all the extraneous info (dept. manager, etc...)

Also add that this project is funded throough DOE SunShot program.

Also, what does this reference refer to?
Andrea Ambrosini, 7/26/2013

aa18 Make this a separate heading (Summary&Future Work)

Add your key results

Bulletize

Add:
- strucutral charaterization (SEM, XRD)
- aging studies at high temperature (600-800C) to investigate durability and stability
-on-sun testing at Sandia solar furnace
Andrea Ambrosini, 7/26/2013

aa22 What does this figure represent (e.g. give it a title).
Andrea Ambrosini, 7/26/2013