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Development and Testing of High-Temperature Solar Selective Coatings

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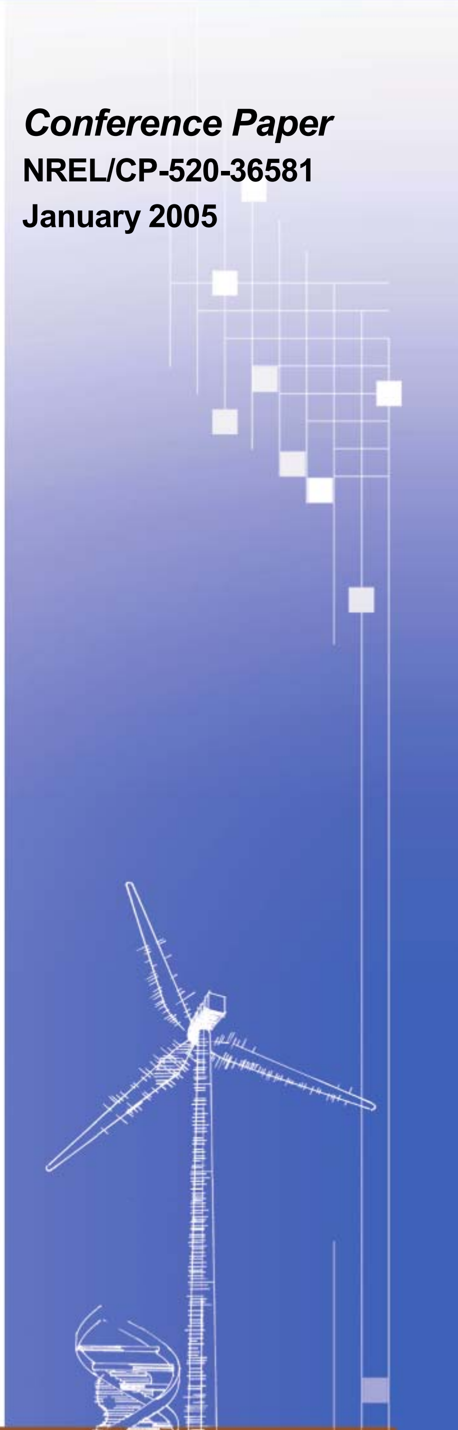

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Development and Testing of High-Temperature Solar Selective Coatings

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ABSTRACT

The Solar Energy Technologies Program is working to reduce the cost of parabolic trough solar power technology. System studies show that increasing the operating temperature of the solar field from 390º to >450ºC will result in improved performance and cost reductions. This requires the development of new more-efficient selective coatings that have both high solar absorptance (>0.96) and low thermal emittance (<0.07) and are thermally stable above 450ºC, ideally in air. Potential selective coatings were modeled, identified for laboratory prototyping, and manufactured at NREL. Optimization of the samples and high-temperature durability testing will be performed. Development of spectrally selective materials depends on reliable characterization of their optical properties. Protocols for testing the thermal/optical properties of selective coatings were developed and a round-robin experiment was conducted to verify and document the reflectance and high-temperature emittance measurements. The development, performance, and durability of these materials and future work will be described.

1. Objectives

Improving the properties of the selective coating on the receiver represents one of the best opportunities for improving the efficiency of parabolic trough collectors and reducing the cost of solar electricity. As discussed in the Solar Program Multi-Year Technical Plan [1], to achieve long-term goals, the cost of the current solar collector technology needs to be reduced by half and the annual solar field efficiency increased by 15%. The efficiency of this technology will be increased and the cost reduced if the solar field operating temperature is increased from 400º to >450ºC. Current coatings do not have the stability and performance necessary to move to higher operating temperatures. The objective of this activity is to develop new, more-efficient selective coatings with both high solar absorptance (>0.96) and low thermal emittance (<0.07) that are thermally stable above 450ºC, ideally in air, with improved durability and manufacturability and reduced cost. An additional objective is to develop the protocols for testing the thermal, optical, and stability properties of the selective coating.

2. Technical Approach

2.1 Development of solar selective coating

To identify potential high-temperature selective coatings, we reviewed the literature [2]. Computer-aided design software was used to optically model the coating thickness and composition of the most promising candidates. Our experimental work focused on modeling high-temperature solar selective coatings, depositing the modeled coatings, obtaining data to validate predictions and estimates, and re-optimizing the coating to meet the desired specifications. The deposition parameters are responsible for the microstructure, which, in turn, determines the optical and mechanical properties of the film layer. During the development of the coatings, the composition, morphology, optical, and physical properties of the individual layers and coatings were characterized to optimize the optical and durability properties of the solar selective coatings.

2.2 Characterization/durability testing

Development of spectrally selective materials depends on reliable characterization of their optical properties. Using standard spectrophotometers, solar reflectance is usually measured in the 0.3–2.5-µm wavelength range at near-normal angle of incidence. The key for high-temperature usage is low , because the thermal radiative losses of the absorbers increase proportionally by the fourth power of temperature. Emittance is frequently reported from reflectance data fitted to blackbody curves. It is important that the room-temperature reflectance measurements are accurate and the calculated data are verified with high-temperature emittance measurements before using high-temperature emittance calculated from room-temperature data for each selective coating. To verify the accuracy of the room-temperature reflectance and high-temperature emittance measurements, a round-robin experiment was conducted with four solar selective receiver materials with four laboratories with infrared (IR) reflectance and high-temperature capabilities: NREL's FTIR laboratory, Sandia National Laboratories (SNL), AZTechnologies (AZT), and Surface Optics Corporation (SOC).

3. Results and Accomplishments

3.1 Development of solar selective coating

Multilayer coatings were modeled because they were significantly easier to model than cermets, with plans to convert the best multilayer design into a cermet later. We reviewed the material properties of candidate materials for the solar selective coating design and materials with low thermal stability and high reactivity were down-selected; materials with more suitable properties were modeled. The original concept did not work as well as hoped, but we found a low-emittance, high-temperature material that, when modeled, gave solar selective coatings with excellent emittance; however, the absorptance of modeled coatings was lower than desired. With further refinement, a simplified multi-layer design resulted in $\alpha = 0.959$ and $\varepsilon = 0.061$ at 400 C [3]. This basically exceeds the goal specification by about 1% overall because 1% in emittance is worth about 1.2% in absorptance. The key issue becomes trying to make the coating. Further improvements are expected by incorporating improved AR coatings, cermets, and textured surfaces; however, trade-offs exist between low emittance and high absorptance.

We are in the middle of calibrating materials- and thickness-monitoring equipment; checking the n and k values; verifying the thickness and uniformity; and checking optical properties, stoichiometry, and morphology of the individual layers for the construction. After we have characterized the individual layers, we will deposit the advanced construction, compare the measured properties with the model, and make further refinements to the model and coating deposition.

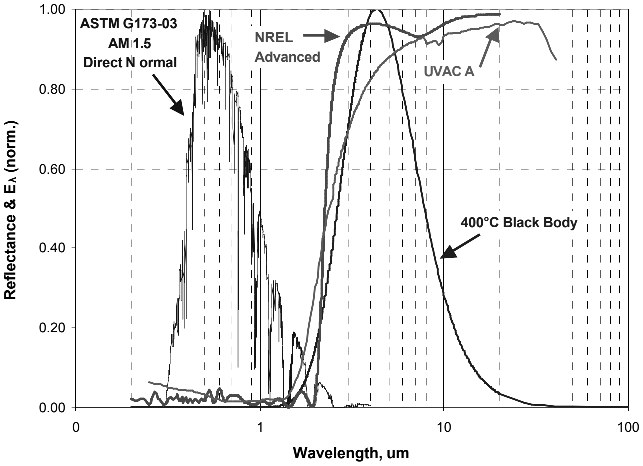

Fig. 1. Improvements in advanced NREL selective coating gives modeled coating with $\alpha = 0.959$, $\varepsilon = 0.061$ at 400 C.

3.2 Characterization/durability testing

AZT, NREL, and SOC measured tube samples of UVAC A, UVAC B, Luz Cermet, and Black Ni at room temperature, where each sample was cut into four 90-degree sections. Measurements were taken on each 90-degree section. SOC measured UVAC A at incident angles of 15º, 30º, 45º, and 60º at room temperature from 0.3 µm to 26 µm. NREL and SOC made measurements on UVAC A from 1.5 µm to 26 µm at 200ºC, 400ºC, and again, at room temperature after being heated. SNL still needs to measure the samples. Correlating the geometry corrections, comparing the AZT, NREL, SOC, and SNL (when received) data, comparing the high-temperature measurements with the blackbody calculations, and comparing incident angle with near-normal measurements, then writing a final report summarizing the results and conclusions still need to be done.

An important requirement for the absorber coatings is long-term thermal stability above 450ºC, ideally in air. At high temperatures, thermal emittance is the dominant source of losses, and the requirement of low emittance often leads to complex designs that are frequently susceptible to degradation at the working temperature. To determine the durability and thermal stability of the spectrally selective coatings being developed, a high-temperature inert-gas oven was purchased and installed that will allow the coatings to be exposed at their operating temperatures and conditions for longer periods of time. The oven has a temperature range of +1100ºF (+593ºC) in an inert-gas environment [N_2, Ar, CO_2, He, and forming gas (a mixture of H_2 and N_2)].

4. Conclusions

The long-term goal is to develop new, more-efficient selective coatings that have both high solar absorptance (>0.96) and low thermal emittance (<0.07) and are thermally stable above 500ºC, ideally in air; such coating will thus allow an increase in the solar fields operating temperature from 400º to >450ºC, leading to improved performance and reduced cost of solar parabolic troughs. Solar selective coatings with optical properties exceeding the goals (absorptance 0.959 and emittance 0.061 at 400ºC) have been modeled for materials with high thermal stability. This exceeds the goal specification by about 1% overall because 1% in emittance is worth about 1.2% in absorptance. The key issue then becomes trying to make the coating. The constituent layers have been deposited and characterized in preparation to depositing the modeled selective coating stack on the NREL multi-chamber deposition system. To perform durability testing on the coatings, a high-temperature (600°C) inert gas oven has been purchased and installed. To verify and document the room-temperature reflectance and high-temperature emittance measurements, a round-robin experiment was conducted with four laboratories with high-temperature capabilities: AZT, NREL, SNL, and SOC.

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[1] *Solar Energy Technologies Program Multi-Year Technical Plan, 2003-2007 and Beyond*, DOE/GO-102004-1775, U.S. Department of Energy, Washington DC, January 2004.

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[3] C.E. Kennedy and H. Price, "Milestone Report: Provide status of test results of candidate solar selective coatings samples and identify promising candidates," NREL/MP-520-36978, Golden, CO: National Renewable Energy Laboratory, 2004.

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