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New cermet coatings for mid-temperature applications for solar concentrated combine heat and power system

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Abstract

New cermet (ceramic-metal) composite coatings have been developed for solar absorbers in a solar concentrating system for combined heat and power operating in a mid-temperature range between 250 to 350 °C. The coatings were applied on stainless steel substrates. Two types of cermet with expected good duration properties were chosen: Nb-TiO_2 and W-SiO_2. The basic layer-structure concept consisted of four sub-layers, counted from the substrate: molybdenum infrared reflector, high metal concentration cermet of either Nb-TiO_2 or W-SiO_2, low metal concentration cermet of either Nb-TiO_2 or W-SiO_2 and SiO_2 antireflection layer. The results from optimised coating fabrication gave solar absorptance and thermal emittance of 0.93 and 0.09 respectively for the Nb-TiO_2 cermet and 0.91 and 0.08 for the W-SiO_2 cermet based absorbers. Annealing at 350 °C did not change the absorptance but decreased the thermal emittance with 0.01 units. Adhesion to substrate and between sub-layers was good and even improved after annealing. In a next step up-scaling to deposition on tubes has been made for the Nb-TiO_2 cermet type coating and such absorbers are now operating in the solar concentrating combined heat and power demonstration plant in Malta.

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Keywords: solar absorber; cermet coating; sputtering-deposition

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1. Introduction

Solar heating is in many respects a mature technology for domestic hot water and space heating operating at low temperatures, i.e. 50 to 100 °C. Solar heating systems for higher temperatures, such as for electricity generation have still a potential fro improving both components and whole systems. There has been a trend during the first decade of the 21th century to invest in large plants for STE (solar thermal electricity) in sun-belt regions in Europe, Asia, US and Australia. Most effort has been put on reducing costs for the concentrating elements (mirrors or lenses), tracking parts and the electricity generation part or heat storage. Less has been done to develop the solar absorbers, the technology so far has mostly been relying on the developments done during 1980th, the pioneering period of solar electricity technology.

This study focuses on new efficient coatings for solar absorbers to be used in STE trough concentrating systems, where the absorber is a stainless steel tube, vacuum encapsulated and located in the focal line of the trough parabolic reflector (or linear fresnels lenses). These systems can operate from 350°C depending on the thermodynamic cycle used for converting heat to electricity.

1.1. Absorbers in concentrated solar collectors for combined heat and power

The development of a new cermet based solar absorber is a part of the FP7 EU project DiGeSPo (Distributed CHP Generation from small size concentrated Solar Power), a modular 1 to 3 kW_e, 3 to 9 kW_{th} micro combined heat and power system for single and domestic dwellings. It integrates a small scale concentrating solar collector module with sixteen collector tubes operating in the range of 300 to 325°C. The system has been set-up for demonstration at ArrowPharma industrial plant in Malta. The development of the absorber coatings for these collectors will be presented in this conference report. The goal was to achieve a solar absorptance of 0.93 in combination with thermal emittance at 350°C of 0.06.

1.2. Previous work

The prevailing type of coating used in mid-temperature applications has been a cermet (ceramic-metal) composite of Mo-Al_2O_3.[1] This coating has recently been improved by replacing the infrared reflector coating with silver, stabilised with thin silicone dioxide layers to prevent degradation.[2] The emittance at 380°C could then be lowered from 0.13 to 0.06, but in combination with a solar absorptance that decreased from 0.96 to 0.94. There is only a few new coating concepts reported for STE applications, a W-Al_2O_3 coating with a solar absorptance of 0.94 and thermal emittance of 0.10 at 400°C.[3] The coating is made by sputtering deposition and is reported to be stable in vacuum during a 30-days test at 580°C. Both Mo-Al_2O_3 and W-Al_2O_3 absorber coatings referred to above, consist of three sub-layers for solar absorption: a base cermet layer of higher metal content on the infrared reflector, an intermediate cermet layer with a lower metal content and on top, an antireflection coating of a pure dielectric material.

1.3. Outline of study

The main steps in this study to optimize a cermet structure using one or two cermet layers are outlined as follows. First absorber coatings were modeled theoretically in order to select feasible materials composition in the cermets, i.e. choice of metal and dielectric component respectively. As the next step the optical constants of the selected cermet components were determined, as we expected a deviation of optical properties of sputter-deposited thin films compared to bulk properties found in literature. A second round of modeling was then performed with these optical constants to derive cermet coating thicknesses and metal contents. After that absorber coatings were deposited according to these parameters from the modeling. A comprehensive article will be published later on all details in the cermet development in the DiGeSPo project. Here we will focus on the main results concerning optical properties, mechanical properties and stability at operation temperatures for the two cermets that was selected as main candidates for being applied in the collectors of the pilot plant at Malta: W-SiO_2 and Nb-TiO_2 cermets. For