Topical Symposium on Sustainable Surface Engineering
Room Town & Country C - Session TS3-FrM

Solar Thermal Conversion

Moderators: Telmo Echániz, University of the Basque Country, Spain, **Marcus Hans**, RWTH Aachen University, Germany

8:00am **TS3-FrM-1 Application of Surface Engineering Solutions in Concentrating Solar Power Key Components***, **Ramón Escobar-Galindo (rescobar1@us.es)**,* University of Seville, Spain*; J. Sanchez-Lopez, T. Rojas,* CSIC-University Sevilla, Spain*; H. Barshilia,* CSIR-National Aerospace Laboratories, India*; M. Krause,* Helmholtz Zentrum Dresden-Rossendorf, Germany **INVITED**

Thermal conversion of solar energy into electricity is one of the most efficient methods of harvesting renewable energy. In this regard, the development of new materials is crucial to improve the performance of concentrating solar power (CSP) plants. The future developments of thermosolar plants demand, among others, (1) mirrors with higher reflectivity, better protection, and lower costs, (2) absorber receiver components operating at higher temperatures, with wavelength selective capabilities, or (3) more stable materials under corrosive environments (i.e. molten salts) (see Figure 1). In this presentation, a review of surface engineering concepts (i.e. tailoring of multilayer materials, control of the interface design) applied to thermosolar energy will be discussed. Examples from our own research on the design, characterization, and thermal testing of ultra-reflective dielectric multilayer mirrors[1] and solar selective coatings (SSCs) for high-temperature applications[2,3,4] will be presented. In the former, we have demonstrated the design, using a genetic algorithm, and manufacture, using Physical Vapour Deposition (PVD) techniques, of metal-dielectric multilayered solar mirrors that can outperform silver reflectors commonly employed in thermosolar and photovoltaic systems. In the latter, the thermal stability of SSCs based on metal oxynitrides prepared by PVD was studied after high-temperature annealing of the samples performed in air (*ex-situ*) and in vacuum (*in-situ*).

(1) A. Jiménez-Solano et al. *Aperiodic Metal-Dielectric Multilayers as Highly Efficient Sunlight Reflectors*. **Advanced Optical Materials** 5,9 (2017) 1600833

(2) T.C, Rojas Ruiz et al. *High-temperature solar-selective coatings based on Cr(Al)N. Part 2: Design, spectral properties and thermal stability of multilayer stacks*. **Solar Energy Materials & Solar Cells. 218** (2020) 110812

(3) R. Escobar-Galindo et al. *Solar selective coatings and materials for high-temperature solar thermal applications*, **Chapter 13 in "Sustainable Material Solutions for Solar Energy Technologies",** Elsevier, 2021

(4) K. Niranjan et al. *WAlSiN-based solar-selective coating stability-study under heating and cooling cycles in vacuum up to 800 °C using in situ Rutherford backscattering spectrometry and spectroscopic ellipsometry.* **Solar Energy Materials & Solar Cells**. 255 (2023) 112305

8:40am **TS3-FrM-3 Development and Thermal Characterization of High-Temperature Coating Materials for Solar Thermal Energy Conversion***, **Renkun Chen (rkchen@ucsd.edu)**,* University of California, San Diego, USA **INVITED**

Coating is fundamentally important and ubiquitous for solar thermal energy conversion. From low temperature solar water heaters to intermediate parabolic trough solar collectors to high temperature solar towers, solar absorbing coatings play an important role. In this presentation, I will introduce our work over the past few years. Specifically, we have developed coatings based on high-temperature stable spinel oxide nanoparticles with ultra-high solar absorptance. The spinel oxide nanoparticles are synthesized with a scalable hydrothermal process. In the first application, the particles are mixed with silica resin to form a slurry for coating. The slurries can be spray coated onto substrates with a scalable process followed by standard curing and sintering processes. The coating on steel and Inconel substrates shows high solar absorptance (with solar to thermal conversion efficiency over 90% for 1000-sun at 800 oC absorber temperature). The coatings also exhibit superior thermal stability after long thermal isothermal ageing tests at 800 oC and thermal cycling tests from room temperature to 800 oC. This scalable coating process can be applied to cylindrical solar collector tubes with liquid heat transfer fluid (e.g., molten salts) in solar towers. In the second application, the black spinel nanoparticles are coated onto particulate heat transfer media (HTM) based on sand or ceramic particles of a few hundred microns in diameter. The black coating can greatly enhance the solar absorptance of sand HTM, and can also lead to stable solar absorptance of Carbo ceramic particles. We also developed high-entropy version of black nanoparticles which show remarkable stability against grain growth and can be used to coat thermochemically active particles to simultaneously increase the solar absorptance and suppress particle sintering, which is important to sustain high reaction kinetics of the thermochemical materials.

9:20am **TS3-FrM-5 Smart Coatings for Concentrated Solar Thermal: from Optical Design and Plasma Synthesis to Performance and Durability Assessment***, **Audrey Soum-Glaude (Audrey.Soum-Glaude@promes.cnrs.fr)**, A. Diop,* PROMES-CNRS, France*; A. Mahammou, D. Ngoue,* PROMES-CNRS, Perpignan University, France*; A. Grosjean,* EPF Montpellier, France*; B. Plujat, S. Quoizola,* PROMES-CNRS, Perpignan University, France*; A. Bousquet, E. Tomasella,* University Clermont Auvergne, France*; L. Thomas,* PROMES-CNRS, Perpignan University, France **INVITED**

Half of our energy consumption is heat for industrial processes and buildings. Contrary to solar PV and wind where electricity is directly produced, in solar thermal technologies, solar radiation is harvested by a solar receiver and converted into heat. In concentrated solar thermal (CST) technologies, solar radiation is concentrated by mirrors on the receiver to increase temperature. The generated heat can be stored more efficiently and at lower cost than electricity, providing great dispatchability and mitigating the intermittency of the solar resource. Solar thermal is thus a major solution for sustainable energy production, complementary to PV and other renewables. Additionally, the hybridization of PV and CST solar technologies can take advantage of the low cost of PV electrical production and the thermal storage of CST to produce both electricity and heat on demand.

To increase solar-to-heat conversion efficiency, the metallic surface of CST receivers can be covered with Solar Selective Absorber Coatings (SSACs) with high absorptance (i.e., low spectral reflectance) in the solar range, and low thermal emittance (i.e., high spectral reflectance) in the infrared range to limit radiative thermal losses. These coatings must also be resistant to high temperatures in air and high thermomechanical stresses, particularly for CST where they are exposed to harsh working conditions for long durations.

Similarly, for PV/CST hybridization, compact systems where PV cells are installed on solar concentrators to produce electricity, and CST thermal absorbers placed at their focus to produce heat, require spectrally selective mirror coatings. The latter must transmit part of the solar radiation to the underlying PV cells (typically from 400 to 1100 nm) and reflect the rest towards the CST thermal solar receiver.

In both types of surfaces, such spectrally selective behavior is obtained by combining advanced optical design and optimization of the coatings with their experimental synthesis, microstructural and thermo-optical characterization, and aging studies including aging under representative solar irradiation. In this paper, this complete development strategy will be illustrated with two examples of coating developments carried out at PROMES-CNRS laboratory: $[W/SiCH]_n$ and $W/WSiCH/TaO_xN_y$ multilayer stacks for CST high temperature SSACs and $[SiO_2/TiO_2]_n$ for selective "PV mirrors" for PV/CST hybridization, deposited by PVD and PECVD techniques.

10:20am **TS3-FrM-8 Controlling Infrared Emissivity of Thermochromic VO_2 Films via V_2N Precursor Thickness for Enhanced Solar Thermal Regulation***, A. Garcia-Wong, D. Pilloud, S. Bruyère, S. Migot, S. Hupont, F. Capon,* ***Jean-François Pierson (jean-francois.pierson@univ-lorraine.fr)**,* Institut Jean Lamour - Université de Lorraine, France

The control of infrared (IR) radiation is crucial for applications related to solar radiation. Thanks to the IR properties modification during its metal-insulator transition, monoclinic vanadium dioxide (m-VO_2) is an excellent material for solar thermal regulation device development. Yet, these applications are linked to substrate IR properties on which the VO_2 is deposited.

In this study, we propose a novel method for tuning the sign of the VO_2 IR-emissivity without changing the substrate. Thermochromic VO_2 films have been synthesized by air oxidation of reactively sputtered V_2N films deposited on silicon substrates. As-deposited vanadium nitride films have been oxidized in air at 550 °C. The structure of the VO_2 films has been characterized using X-ray diffraction and Raman spectrometry. Transmission electronic microscopy combined with electron energy loss spectroscopy (EELS) bring relevant information to describe the oxidation mechanism of V_2N. At the interface between the remaining V_2N film and the formed VO_2

one, a thin layer of VN of 20 nm thick has been evidenced. At this oxidation temperature, the annealing duration to obtain efficient thermochromic VO_2 films is fixed to 3 minutes. The initial precursor (V_2N) thickness is the key parameter for tuning the IR properties. V_2N films with low thickness allow the formation of thermochromic VO_2 films with negative emissivity switch (approx. -0.2) while thick V_2N films allow positive emissivity switch (approx. 0.2). Our findings introduce a different strategy for IR emissivity control on thermochromic devices.

10:40am **TS3-FrM-9 Emissivity and Reflectivity Measurements of Coatings for Solar Applications**, ***Telmo Echaniz (telmo.echaniz@ehu.eus)***, *I. Gonzalez de Arrieta, M. Sainz-Menchon, J. Gabirondo-Lopez, G. Lopez,* University of the Basque Country, Spain

Widespread adoption of concentrated solar power relies on lowering its operational costs, which requires efficient absorbing materials capable of withstanding high temperatures. This motivates the development of coating materials based on oxides. Unfortunately, these materials do not always feature appropriate optical properties, which means that strategies to increase their solar absorptances must be carried out. This work reports on the optical characterization of high-absorbing coatings. For that, directional spectral infrared emissivity measurements up to 600 ºC, integrating sphere and bidirectional reflectance measurements in the UV-Vis-NIR range at room temperature have been performed. Spectral directional emissivity measurements were performed in the HAIRL emissometer using using a DTLaGS detector between 1.43 and 25 µm and the sample was placed between 10 and 80º every 10º for each directional measurement [1]. This emissometer is equipped with a Bruker Vertex 80v FTIR spectrometer that possesses an IR integrating sphere. Once the spectra were obtained, the emissivities were integrated along the electromagnetic spectrum and the solid angle to obtain total hemispherical emissivity values. Bidirectional reflectance measurements were performed between 350 and 2500 nm in a Cary UMA device. They were measured in both s and p polarizations, from which the unpolarized reflectance function was reconstructed. Measurements in the off-specular directions were also measured to complement these data and allow estimation of the total reflectance, weighted by the solar spectrum. Both the infrared emissivity and the BRDF measurements allowed obtaining the conversion efficiency.

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References: [1] I. González de Arrieta et al., Metrologia 57 (2020) 045002

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