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# Efficiency and behavior of textured high emissivity metallic coatings at high temperature

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ABSTRACT

Three metallic coatings with textured surfaces, made of rhenium, tungsten and molybdenum, were studied in the frame of the Solar Probe Plus mission (NASA) as candidate materials. The role of these coatings is to dissipate a maximum of energy from a hot instrument facing the Sun, by the mean of their high total hemispherical emissivity. The total hemispherical emissivity of the three coatings was measured in the temperature range 1100–1900 K, as well as over time in order to study their high temperature stability. Various emissivity levels were obtained depending on the surface texture. The highest total hemispherical emissivity was obtained on a rhenium coating, with an emissivity of 0.8 in the temperature range 1300–1700 K. However, this rhenium coating with a fine, sharp surface texture, presented an instability at high temperature, which might limit its optimal operating temperature to about 1500 K. As for the tungsten coating, the total hemispherical emissivity was increased by a factor 2 due to the enhanced surface texturation and its great stability over the whole temperature range was shown.


## 1. Introduction

The Solar Probe Plus mission (NASA) is an incoming mission of space exploration dedicated to the study of the Sun. With a launch planned for 2018, the spacecraft will progressively get closer and closer to the Sun, up to 6 million kilometers (8.5 solar radii Rs) from the Sun's surface, in order to perform in situ measurements directly inside the solar corona. A set of instruments will be accommodated on the spacecraft to perform the measurements, among them the Solar Probe Cup, as part of the SWEAP instrumentation (Solar Wind Electrons Alphas and Protons investigation, led by the Smithsonian Astrophysical Observatory, Univ. Harvard, USA). The Solar Probe Cup will face the Sun at all time during the mission, and thus get very hot at closest approach because of the intense solar radiation (up to 700 kW m$^{-2}$ at a distance of 8.5 Rs). Coating the sides of the Solar Probe Cup, not exposed to the Sun's radiation, with a high emissivity coating, appears as a good way to lower its temperature.

Among refractory metals, the wavelength distribution of the spectral emissivity shows only little differences from a metal to another [1], which often limits their efficiency in thermal radiation systems. To find a solution to this lack of variety, a new research field has recently emerged based on the dependence of the emissivity to the surface topography, and aiming at the production of metallic surfaces of controlled emissivity. This emissivity control is commonly achieved via periodic patterns at the micron scale, falling generally in four main categories depending on their geometry: surface gratings [2], one-dimensional [3], two dimensional [4–6] and three dimensional structures [7]. Various applications of these surfaces are possible as the emissivity can be tuned in different ways, increasing the efficiency of different energy conversion devices. As an example, the spectral emissivity can be enhanced specifically in the short wavelength region [4,8,9], thus increasing the efficiency of selective solar absorbers for solar energy conversion and visible light emitting devices. The emissivity can also be enhanced in a wide spectral range [6], increasing the efficiency of radiating cooling systems.

In the case of the Solar Probe Plus mission, a coating with the highest possible emissivity, in a wide spectral range from visible to far infra-red, with no spectral selectivity is looked for, as well as a good stability at high temperature over time. The coatings selected for this study were produced by Ultramet (CA, USA), and are typically used on the outside of chemical rocket engines to keep cool the walls. The goal of this study is to characterize the emissivity of these coatings as well as to study their stability at high temperature in high vacuum. This study also aims at helping to further understand the complex relationship between surface topography and emissivity by producing new and valuable experimental data at high temperature.

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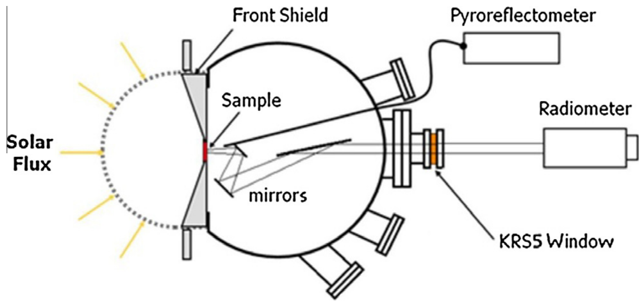


**Fig. 1.** Scheme of the MEDIASE facility in the emissivity measurement configuration, which is the configuration used for this study.

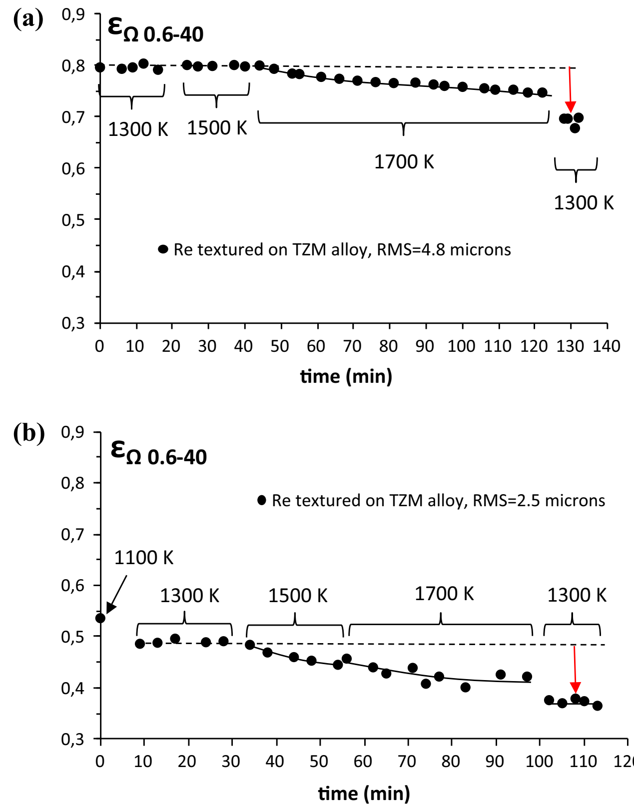


**Fig. 3.** (a and b) Total hemispherical emissivity of textured Re coatings deposited on TZM alloy as a function of temperature and time. Two different emissivity values and high temperature behaviors were found, corresponding to two different surface structures. The corresponding SEM pictures are presented respectively in Fig. 4 for (a) and in Fig. 5 for (b).

## 2. Experimental set-up

The MEDIASE facility (Fig. 1) has been designed and instrumented to reproduce the conditions expected near the Sun [10–12]. This test facility is placed at the optical focus of the 1 MW solar furnace in Odeillo, France. Samples of various materials can be heated up to 2500 K using the solar concentrated radiation, through a hemispherical silica-glass window (35 cm in diameter) placed in front of the chamber. The MEDIASE set-up is composed of a chamber (0.06 $m^3$) equipped with a turbo-molecular pumping system to work in high vacuum up to $10^{-4}$ Pa. The front face of the chamber and the sample holder are water-cooled, while the heat flux exchange between the heated sample and the sample-holder is minimized using three ceramic/metallic needles that maintain the sample. The facility can be instrumented to perform the following measurements, all on the back face of the sample: temperature, directional total, or spectral, or in narrow ranges emissivity using a Heimann KT4 radiometer, mass spectrometry, and mass loss via a Quartz Crystal Microbalance. The temperature is measured with a bi-color optical fiber pyro-reflectometer developed at PROMES-CNRS [13]. Finally, tubes at 30° and 45° to the normal of the sample surface have been placed around the chamber to accommodate the treatment instruments: the Thermo-Fisher EX05 ion gun and the Omicron HIS13 VUV source (not used in this study).

Before performing emissivity measurements with MEDIASE, the radiometer is first calibrated on a blackbody. This calibration is done in a way that the entire optical path of MEDIASE is reproduced on the calibration bench. The bi-color optical-fiber pyro-reflectometer is also calibrated, but because of its complex functioning [13], it requires two separate calibrations: one on a blackbody and one on a reflectivity calibration bench using reference reflectivity samples (Labsphere references). The bi-color optical-fiber pyro-reflectometer, in opposition to classical pyrometers, provides the real temperature of the surface without having to measure or assume first an emissivity or use the gray-body hypothesis: by measuring simultaneously the reflectivity and the radiance of the sample at two wavelengths (1.3 and 1.55 μm), it provides the real surface temperature without knowledge of the emissivity.

## 3. Test samples and protocols

Three different coatings from Ultramet (CA, USA) were tested as candidate materials: rhenium deposited on TZM alloy (0.5% of Ti, 0.08% of Zr and Mo balance), tungsten deposited on tungsten and molybdenum deposited on TZM alloy. A picture of a sample of each

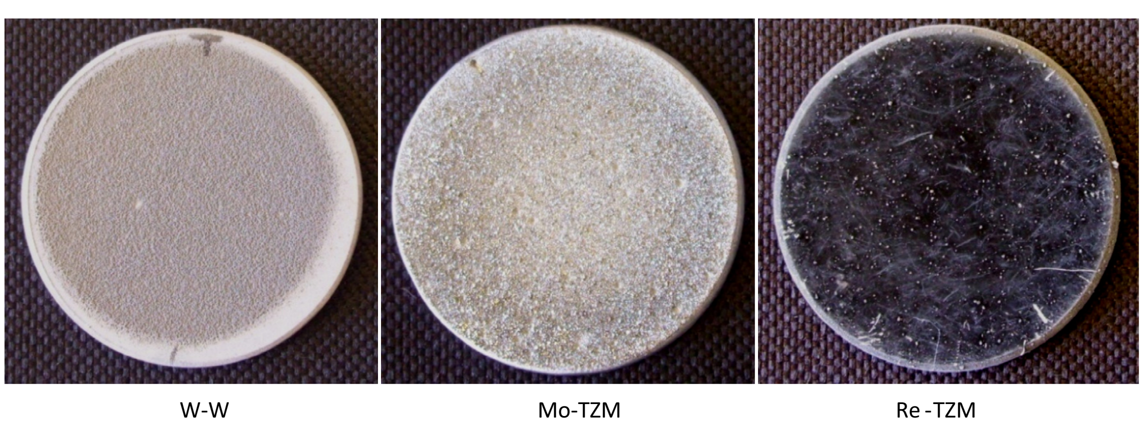


**Fig. 2.** Pictures of a tungsten coated tungsten sample (W-W) (left), a molybdenum coated TZM sample (Mo-TZM) (middle) and a rhenium coated TZM sample (Re-TZM) (right).