Heat Conduction in Porous Absorption Layers for Thermography Applications

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Abstract

Phase transitions in so-called Shape Memory Alloys (SMA) involve an adiabatic temperature change, which can be observed by means of infrared thermography. These infrared investigations can be challenging for metallic samples because one does not only observe the temperature of the sample itself but also reflections from the surroundings. Coating the sample with an infrared absorption layer can eliminate this issue. For small SMA samples with thicknesses of only hundreds of nanometers the heat capacity of a 3 µm thick absorption layer can no longer be neglected. Its effect on the temperature measurement is simulated both for a commercially available carbon lacquer and for a custom developed "Gold black". (Detail of the fabrication process can be found in [1]) The main focus of this work is on the calculation of the difference between the real sample temperature and the observed temperature on the surface of the absorption layer. A typical experimental set-up for the measurement is illustrated in Figure 1.

Since Gold blacks are highly porous, the Heat Transfer in Porous Media interface is used in COMSOL Multiphysics®. A two-dimensional intersection plane of the model geometry is shown in Figure 2. The outer area is in contact with the sample holder (compare with Figure 1). Therefore "Temperature" is chosen as boundary condition. The SMA samples acts as a heat source to the inner circular area of the absorption layer. Hence the "Heat Flux" condition is applied here. The remaining surfaces are treated with the "Surface-to-Ambient Radiation" condition. Unfortunately, automated meshing routines in COMSOL Multiphysics® fail for this geometry since the thickness of the absorption layer is about 1000 times smaller than the lateral dimensions. However manually starting from a two-dimensional free triangular mesh on one of the surfaces and extruding this mesh over the entire volume solves these discretization issues.

The application of commercially available carbon black yields in a 20 µm thick absorption layer on top of 200 nm SMA. From the simulation it can clearly be seen that a heat pulse of 1 K in the SMA results in a temperature change of less than 0.01 K on the surface of the absorber. Since this value is smaller than the accuracy of conventional thermography detectors these carbon blacks are inappropriate for such thin samples.
One the other hand the simulation for the custom made Gold blacks results in a linear relation between the sample temperature and the observed temperature. This relation was calculated for sample temperature between 0.1 K and 2 K (Figures 3, 4).

Carbon blacks are indeed widely used for thermography on bulk material. However, it turns out

these are disadvantageous for thin films. In contrast, a Gold absorption layer does not impede the temperature measurement due to its relatively low density and heat capacity. This COMSOL Multiphysics® simulation identifies a possibility for a direct measurement of the adiabatic temperature change of Shape Memory Alloys in thin films using thermography. To the best of the author's knowledge such a measurement has not been reported yet.

Reference

[1] Walter Lang et al., Absorbing layers for thermal infrared detectors, Sensors and Actuators A, 34, 243 - 248 (1992)

Figures used in the abstract

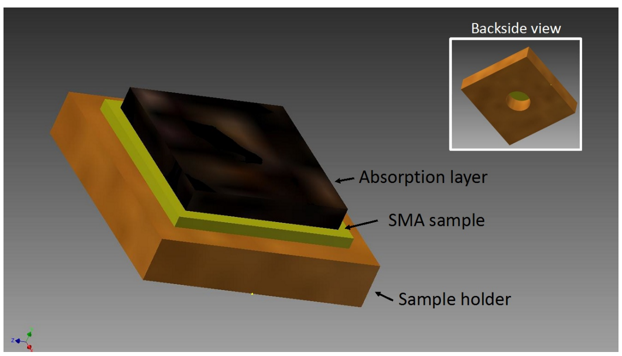

Figure 1: Schematic illustration of the experimental setup (Not to scale). A free-standing film is achieved due to the hole in the sample holder.

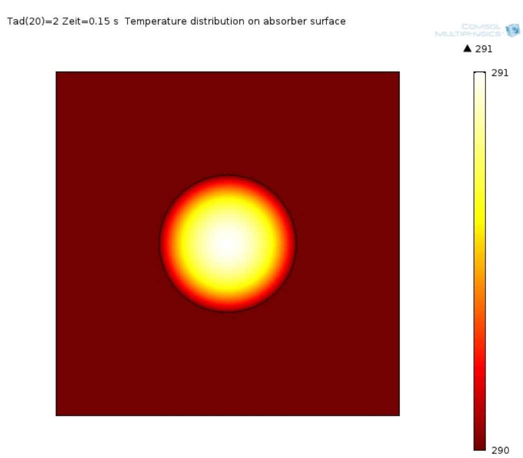

Figure 2: Temperature distribution on the surface of the absorption layer.

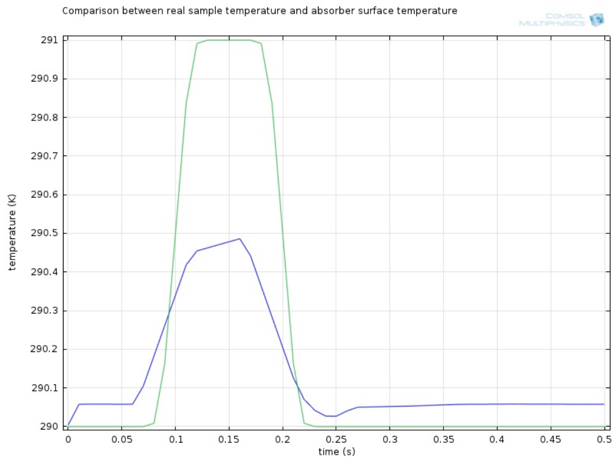

Figure 3: A temperature pulse of 1K in generated in the sample (green curve). The resulting surface temperature of the “Gold black” absorption layer is depicted in blue.

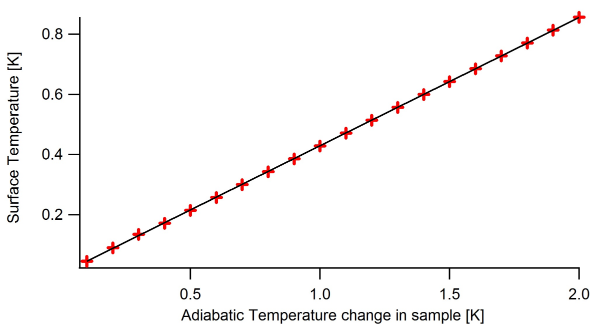

Figure 4: Surface Temperature of “Gold black” as a function of the adiabatic temperature change in the SMA sample with linear regression.