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Universität Bielefeld

Department of Physics, Thin Films & Physics of Nanostructures

Heat Conduction in Porous Absorption Layers for Thermography Applications

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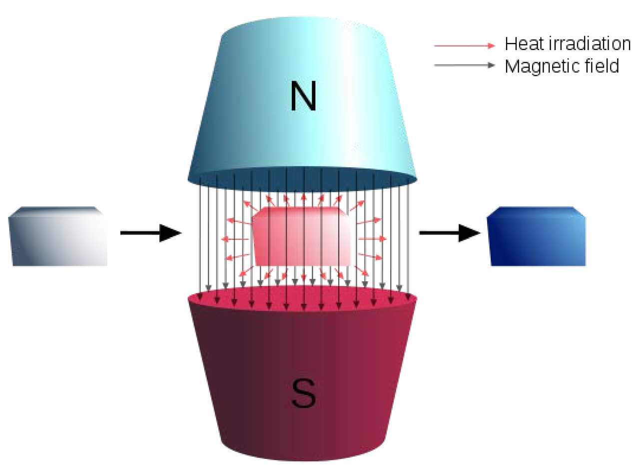
Introduction

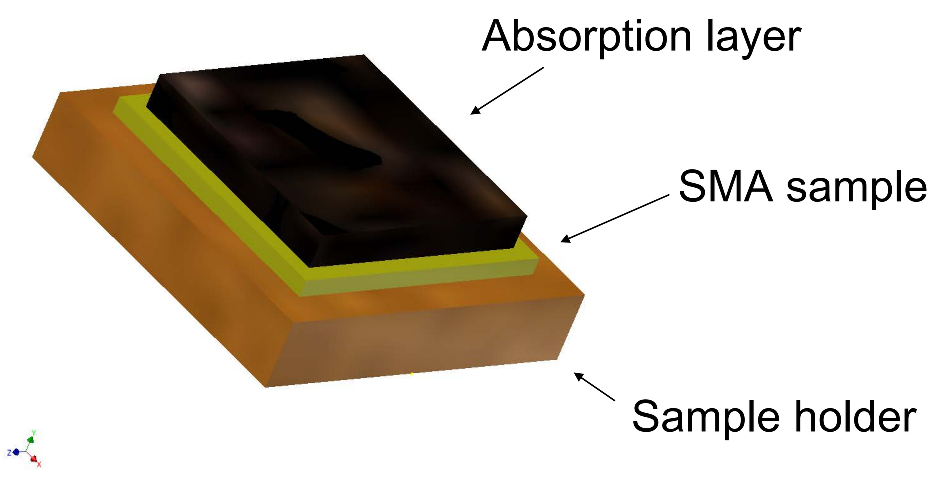
Magnetic Shape Memory Alloys (SMA) are promising candidates for next generation cooling systems. Magnetically induced phase transitions involve adiabatic temperature changes.

In thin film systems these temperature changes can be observed by means of infrared thermography. Unfortunately this method is quite challenging for metallic surfaces due to reflection of infrared radiation from the surroundings.

For small SMA samples with thicknesses of only hundreds of nanometres the heat capacity of a 3µm 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".

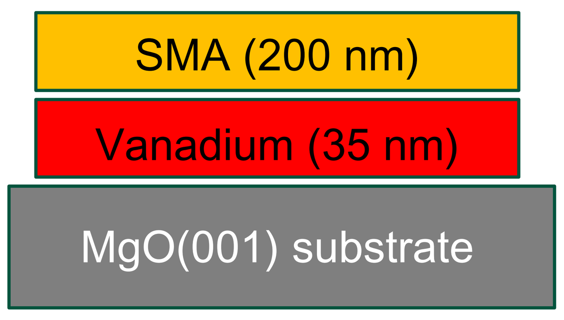
The main focus of this work is on the calculation of the difference between the real sample temperature and the observed temperature on the surface of the absorption layer.





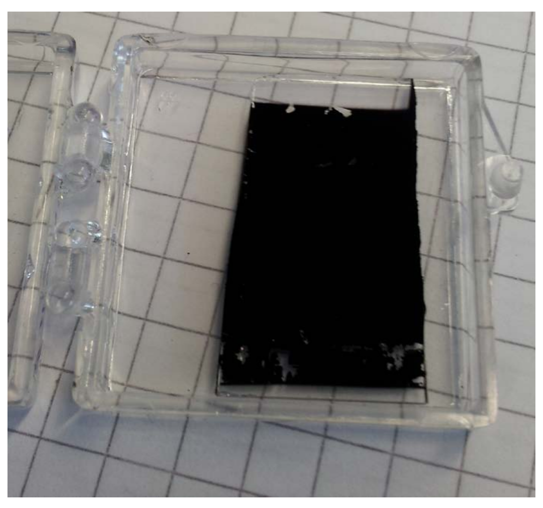
Experimental preparation

Thin film magnetocaloric samples are prepared by magnetron sputtering on a sacrifial Vanadium layer on MgO(001) substrates. Via a selective wet-chemical etching procedure the SMA is removed from the substrate thus resulting in a freestanding layer. This freestanding layer is transferred to a special sample holder with a hole of 1 mm in diameter. [1]

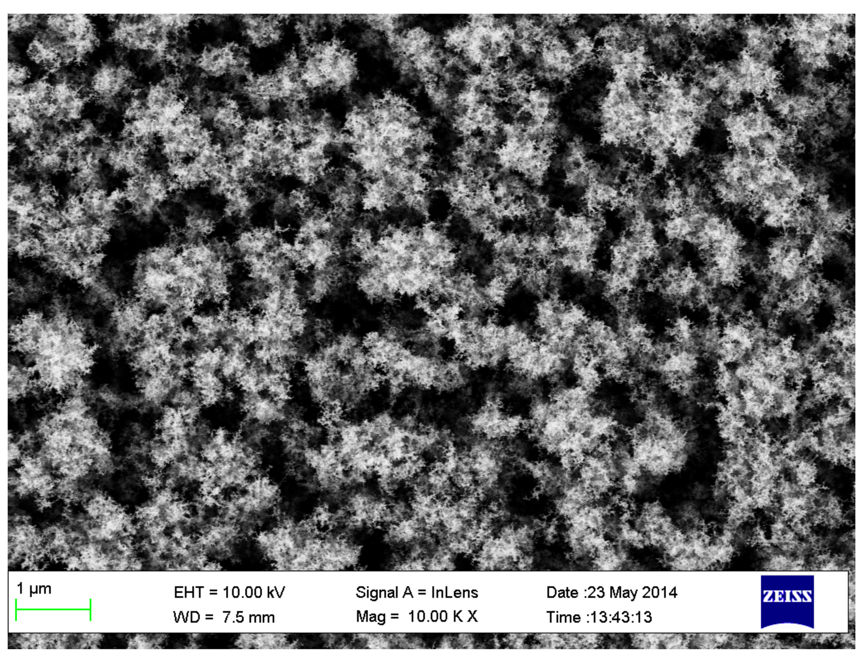


Sketch of the multilayer structure

Subsequently the samples are coated with the a "Gold black" absorption layer in a custom built evaporation chamber. Gold material is evaporated in a vacuum chamber with nitrogen atmosphere of 2 mbar from a molybdenum filament at heating currents of 90 Ampère. Due to collisions with nitrogen atoms gold clusters are formed and being deposited to the sample, thus resulting in a surface with a high roughness. [2]



„Gold black" on glass



SEM Image of Gold black

Simulation

The influence of the "Gold black" absorber is studied by means of the "Heat transfer in porous media" module.

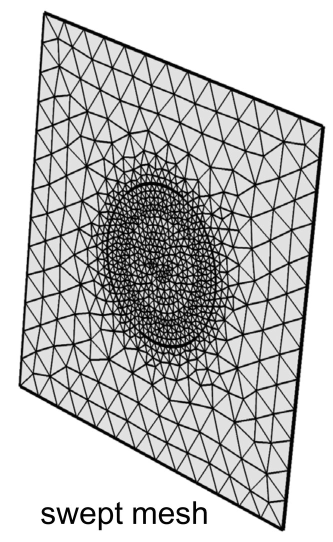
Input parameters are determined experimentally:

- Layer thickness: 3µm (AFM)
- Volume fraction θ_p: 0.05 (SEM)
- Thermal conductivity and heat capacity: bulk values

$$(\rho c_p)_{\mathrm{eq}} \frac{\partial T}{\partial t} + \rho c_p \vec{u} \cdot \vec{\nabla} T = \vec{\nabla} \cdot (k_{\mathrm{eq}} \vec{\nabla} T) + Q$$

$$(\rho c_p)_{\mathrm{eq}} = \theta_{\mathrm{p}} \rho_{\mathrm{p}} c_{p,\mathrm{p}} + (1 - \theta_{\mathrm{p}}) \rho c_{\mathrm{p}}$$

$$k_{\mathrm{eq}} = \theta_{\mathrm{p}} k_{\mathrm{p}} + (1 - \theta_{\mathrm{p}}) k$$



swept mesh

Due to the flat structure (5 mm lateral sizes and 3 µm thickness) automated meshing routines fail. However, a swept mesh is an appropriate choice. A free triangular mesh is applied to one of the surfaces and extruded over the entire geometry.

Boundary conditions:

Heat pulses from the SMA sample in the freestanding area are treated via "Inward heat flux". "Surface to ambient radiation" is applied to the opposite surface of this part of the sample.

The part of the sample which is in contact with the sample holder, i.e. a heat sink, is set to a constant temperature.

Since the IR measurements are performed in vacuum, heat conduction to the environment can be neglected.

Results

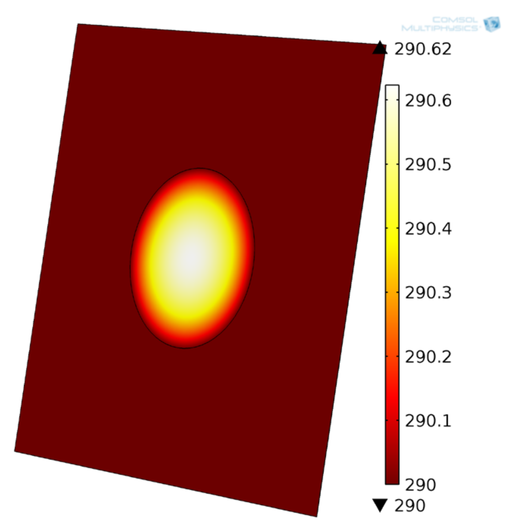
The application of commercially available carbon lacquer yields in a 20µm thick absorption layer on top of 200nm SMA.

A heat puls is induced to the backside of the sample and surface temperature is observed.

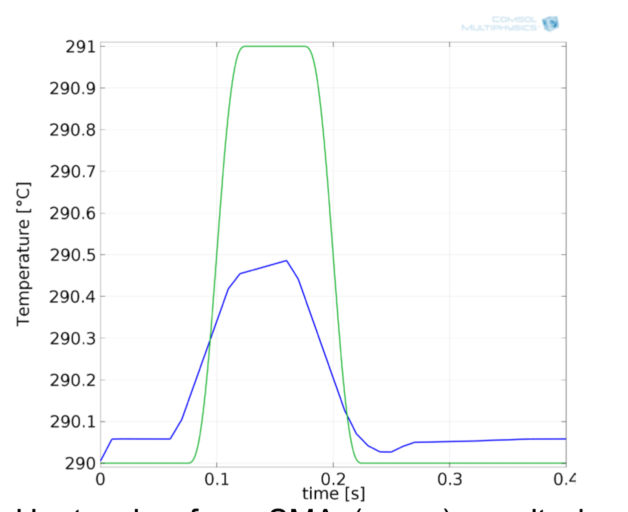
From the simulation it can clearly be seen that a heat pulse of 1K in the SMA results in a temperature change of less than 0.01K on the surface of the absorber. Since this value is smaller than the accuracy of conventional thermography detectors these carbon blacks are inappropriate for such thin samples.

On the other hand simulations for custom made Gold blacks are carried out via a parametric sweep for sample temperature between 0.1 K and 2 K. This study results in a linear relation between the sample temperature and the observed temperature. In contrast to the carbon lacquer, the changes of surfaces temperatures on gold black can be detected via thermography.

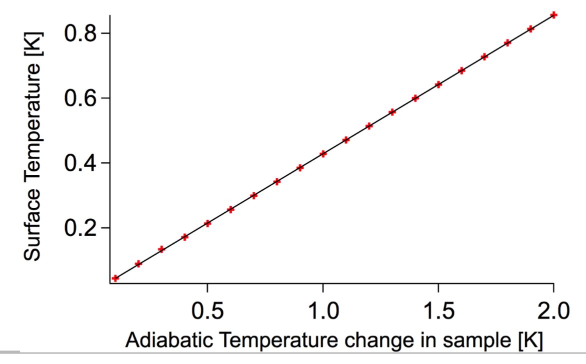
Consequently the result of this simulation can be used to determine the adiabatic temperature change in the SMA sample from the observed surface temperature on the absorption layer.



Surface temperature profile for Gold blacks



Heat pulse from SMA (green) results in a temperature change on the absorber surface (blue)



References and Acknowledgement

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[1] L. Helmich et al., Preparation of freestanding magnetocaloric Heusler thin films and oberservation of the Martensitic transformation, to be published

[2] W. Lang, Absorbing layers for thermal infrared detectors, Sensors and Actuators A, 34, 243 – 248 (1992)

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