Optical Performance of heated laser mirrors for high power lasers

Manuel Haenle*, Andreas Kelm*, Marcel Knopf*, Rainer Boerret*, Stefan Sinzinger**

** Zentrum für optische Technologien, Aalen University,* rainer.boerret@htw-aalen.de; *** TU Ilmenau*

To keep the thermal expansion of mirrors for high power laser within a specified value, a cooling system has to be applied. The idea presented in this paper is, to heat up the mirrors to keep them at high operating temperature. Therefore several simulations were run and verified at specially designed and manufactured test parts. The test parts are fabricated with a type of an economic process chain.

1 Introduction and background

When it comes to industrial applications like welding, cutting or drilling, high-power CO2-lasers have become the state-of-the-art tool. In order to achieve a high quality beam, the mirrors guiding and forming the beam have to be cooled down during operation. In order to simplify the laser head, the idea is to use silicon carbide instead of copper mirrors. Ceramics can be used at much higher temperatures than cooper. The mirror has to be designed in a way, that it achieves its desired form at operating temperature. Then one can leave the cooling system making the head lighter and less complex. In a first step, test-parts are simulated under different conditions and the proof of concept is made by verifying the simulated results in an experimental set-up. The test parts were manufactured by using a new polishing tool for fast processing.

2 Simulation

In a first step, a simple simulation using the finite element method calculated the behavior of different mirrors over time with a constant heating power of 20W simulating the thermal load of a CO2 laser. The equilibrium temperature was 120℃. The same amount of heat was put onto a copper mirror and an already preheated mirror with a temperature of 120℃.

Mirror	Copper	SiC Standard	SiC preheated to 120℃
Simulated deviation	42µm	4µm	1,4µm
Simulated temperature change	100K	100K	15K

Tab. 1 *Overview over simulated surface deviation and temperature change of a copper, a SiC and a preheated SiC mirror with a heating power of 20W.*

Table 1 shows the simulation results. The temperature in equilibrium is independent of the material. Copper shows the largest surface deviation, while a preheated SiC mirror shows almost no deviation.

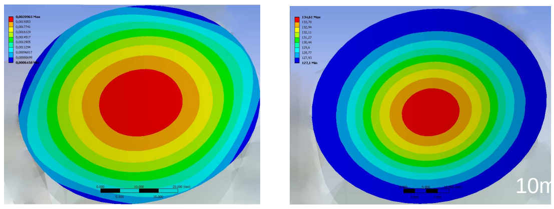

Figure 1 *Simulated surface deviation (max. 1,4µm)and temperature distribution (max. 7K) of the preheated SiC mirror with an additional heat flow of 20 W*

Figure 1 shows the simulated surface deviation and temperature distribution of a preheated SiC mirror with an additional heat flow of 20W. Both suggest a deformation that leads to a change of focal length. Surface deviation is not rotational symmetrical because of clamping.

3 Verification and measurements

To verify the simulation results a test-part was manufactured and measured during heating with a thermo foil. The mirror was heated from the back with a heat flow density of 3W/cm². The temperature was measured with a PTC and a thermo camera. The mirror was heated inside a Fizeau-interferomter, so in situ measurements were possible.

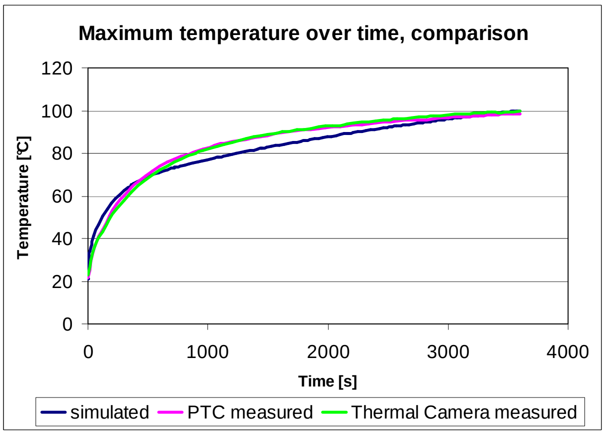

Figure 2 *Comparison of simulated and measured mirror temperature over time. The deviation is a result of the simple simulation model.*

Figure 2 shows the simulated and measured temperature over time. With a load simulating the holding and the interferometer, the two curves show good agreement. The measurement was aborted after one hour.

Figure 3 shows the surface deviation of the mirror when it is heated to 100 °C. The maximum deviation is about 2µm, which is in good concordance with the simulation. The discrepancy between simulation and measurement may be caused by the simple simulation model. As the simulation results suggested, focus is the dominating image error. Higher orders of rotational image errors were negligible. Tilt resulting from deformation of the bearing was removed before analysing.

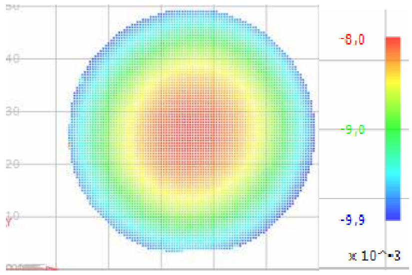

Figure 3 *Measured deformation of the SiC mirror at a temperature of 100°C. The maximum deformation is about 2µm, the main surface error is the focal term. Tilt was removed.*

Since focus is the prime image error, the characteristics of the focus term was surveyed. Figure 4 shows the change of the focus term which is almost linear with temperature.

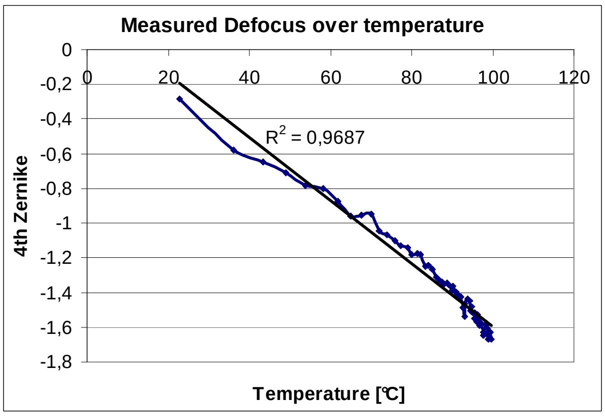

Figure 4 *Typical development of focus (4th Zernike) over temperature. The focus term shows the largest change over temperature.*

4 Manufacturing of the test parts

For manufacturing the test parts a newly developed bond abrasive tool was used. The tool has a concave shape to avoid effects caused by the tool's edge. Figure 4 left shows the tool in action on a mirror surface. The fine grinded surface was polished with diamond slurry to achieve good roughness and high reflectivity. The total processing time for grinding, fine grinding and polishing was about 3 hours.

Figure 5 right shows an interferometric measurement of the test part without heating

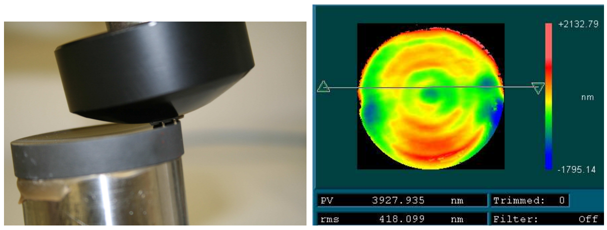

Figure 5 *Newly developed bond abrasive tool used to manufacture the mirror face (left), interferometric measurement of the mirror without heating (right).*

5 Summary and Outlook

In this study a laser mirror made out of SiC under temperature load was simulated and tested. It is shown that focus term shows the largest change. In further studies a mirror will be manufactured which is designed to achieve the ideal form at operating temperature. The surface deviation of this mirror will be examined under an additional thermal load. Furthermore a more sophisticated simulation model will be developed.

Acknowledgement

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