Experimental validation of design parameters of a non-contact thermally actuated deformable mirror.

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Abstract

For an adaptive optics system, a non-contact actuated deformable mirror has been developed. It is based on the principle of thermal expansion; the required energy is applied with a spatially controllable heat source and absorbed by an absorptive layer on top of the mirror substrate, underneath the reflective surface [1]. For the experimental validation of three relevant design parameters sample mirrors have been manufactured. The motivation of the design parameters and the experimental results are presented in this paper.

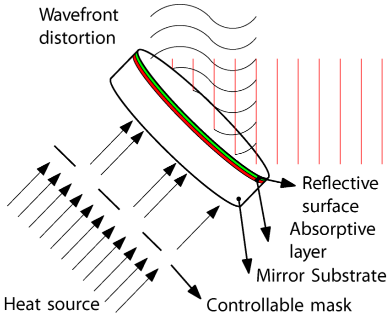
1 Introduction

Adaptive optic systems are well known from their application in ground-based telescope systems for correcting atmospheric wavefront distortions. Less commonly known is their application in lithography, microscopes and high-power lasers that suffer from quasi-static effects like creep, hysteresis and thermal expansion [2]. While the corrections in telescopes work in the frequency range up to a few hundred Hz, we aim to correct the quasi-static phenomena.

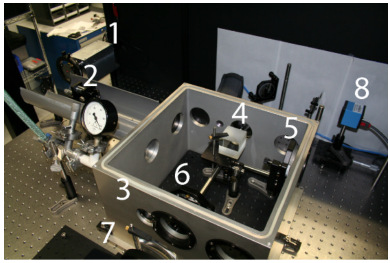
In order to avoid the transmissibility of dynamic vibrations from the environment to the optical components, and to avoid surface deformation during assembly, the actuation mechanism needs to be contactless. The concept of the non-contact thermally actuated deformable mirror is shown in Figure 1(a).

2 Sample configuration

Seven samples are discussed in this paper of which the configuration can be found in Table 1. The behaviour of the substrates is predicted using a FEM model, and can be described by an exponential function. In order to realise an optimal actuator design, the three relevant design parameters were investigated, relative to the benchmark mirror M1, which design is shown in figure 1 (a).



(a)



(b)

Figure 1 (a): The actuation principle: A wavefront-distorted light beam is corrected after reflecting off a deformable mirror. The deformation of the mirror is caused by a spatially distributed thermal profile. It is induced by the absorption of a spatially controllable heat source at the absorptive layer, on top of the mirror substrate, underneath the reflective surface. (b): The experimental setup consists of 1) a HeNe laser; 2) a pinhole-lens combination for beam cleanup; 3) a vacuum chamber to avoid turbulence; 4) a 50/50 beam splitter; 5) a reference mirror; 6) the deformable mirror; 7) the spatially controllable heat source: a video projector; 8) a CCD camera.

The configuration of the seven samples to address the three design parameters are chosen as following (for the exact configuration see Table 1):

1) M2, M3 and M4 are made to evaluate the position of the absorptive layer. If the absorptive layer has a defect, which may cause a non-uniform thermal profile, this design parameter can be used to decrease this effect.

2) In order to evaluate geometrical effects M5 is made thicker and M6 has a larger surface area. Expected is that geometrical effects show no significant difference.

3) M7 is made to validate the effect of different material properties using a Borosilicate substrate. The difference in relevant material parameters, the diffusivity $D = k/(\rho C_p)$ and the relative expansion coefficient $M = \alpha / k$, causes a 20% faster response, and a 40% decreased amplitude compared with BK7. In these parameters k is the thermal conductivity, ρ the material density, C_p the thermal capacity and α the linear thermal expansion coefficient.

Table 1: Sample configuration: M1 is benchmark mirror (figure 1(a)).

Sample	Size [mm]	Material	Position of the absorptive layer
M1	50x50x4	BK7	Top surface
M2	50x50x4	BK7	¼ from top surface
M3	50x50x4	BK7	½ from top surface
M4	50x50x4	BK7	Bottom surface
M5	50x50x8	BK7	Top surface
M6	75x75x4	BK7	Top surface
M7	50x50x3.3	Borosilicate	Top surface

3 Experimental setup

The actuation part of the experimental setup as shown in figure 1(b) consists of a deformable mirror and a spatially controllable heat source. First, an offset heat-flux is created, enabling both heating and cooling of the samples, which causes a bending deformation. Second, the mirror is exposed to a patterns of lines, of which the pitch is decreased from 17 [mm] to 4.5 [mm] in four steps. Each of the measurements is executed until equilibrium of the thermal gradients has been reached.

The measurement part consists of a homodyne Michelson interferometer, with a 45 [mm] diameter laser beam. The measurement and the reference arms have different length, and the light bundle is slightly converging to compensate for the thermal bending of the mirror substrate. The interference pattern is captured with a CCD camera. Each experiment consists of interference patterns that are analysed using a carrier-fringe method [3]. The measurements have an out-of-plane resolution of 2 nm and a spatial resolution of 2 mm.

4 Results and discussion

The line pattern exposure causes a sinusoidal deformation in one direction. The amplitude of the deformation develops over time. This development is fitted with an exponential function, in which the deformation and the time constant are estimated. Figure 2 shows that most of the samples react according the expectation; however M4 and M5 show a large difference in response, which can be explained by the thermal properties of the glue. This hypothesis is validated using a FEM package and therefore it is desirable not to use glue.

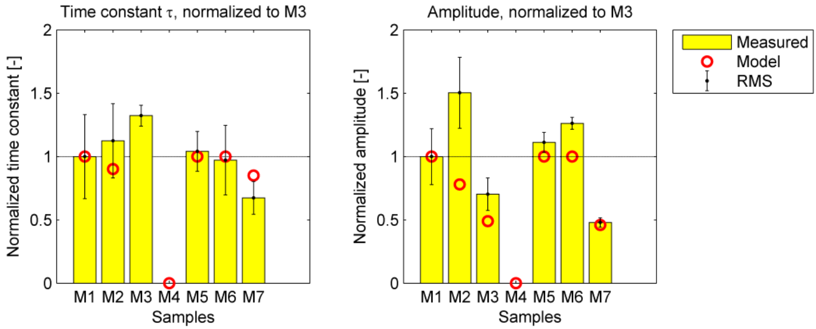


Figure 2: Results: comparison with benchmark sample M3, concerning the time constant and the amplitude of the deformation. M2 shows no deformation. M4 and M5 show a larger deformation than expected and a different time constant, due to the thermal properties of the glue. Substrate M9 has a lower time constant and amplitude because of its thermal properties. M7 and M10 show a slightly higher than expected amplitude, which can be explained by the method used to compare the results.

5 Conclusions

The position of the absorptive layer, the substrate material and the substrate geometry are three design parameters that are relevant for the design of a thermally deformable mirror. The experimental validation expressed in amplitude and time constant of the deformation showed sufficient agreement with the model to use as a design tool.

Acknowledgements:

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References:

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