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Executive Summary

Issue 02

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1 ADAPTIVE DEFORMABLE MIRROR

The Photonics Laboratory of Münster University of Applied Sciences (MUAS) has developed an adaptive deformable mirror based on the unimorph principle in a former GSTP, which was concluded in February 2015 (4000103207/10/NL/EM). From February 2018 to June 2020, a follow-up study by OHB System AG and MUAS took place, which is described in this document. The following activities were performed: requirement consolidation, piezo-material trade-off, optimization of structural design, manufacturing and testing of the deformable mirrors.

Figure 2 shows a schematic view of the redesigned deformable mirror. The mirror is based on an isostatic mounting design with an optical aperture of 50 mm diameter. It is made of a 550 µm thick glass substrate glued to a 700 µm thick piezo-ceramic disc. This thin structure enables considerably larger strokes than most other mirror concepts, allowing to correct for large aberrations. The piezoelectric disc is sandwiched between two metallic electrodes, an unstructured electrode on the front side and a structured backside electrode. The glass substrate is furnished with a dielectric coating with a reflectivity of 99.998 %, which is suitable for high power lasers. The coating is magnetron-sputtered on a super-polished optical glass substrate (rms-roughness < 1.5 Å) that exhibits very low surface scattering. When a voltage is applied to the piezoelectric disc, it contracts or extends

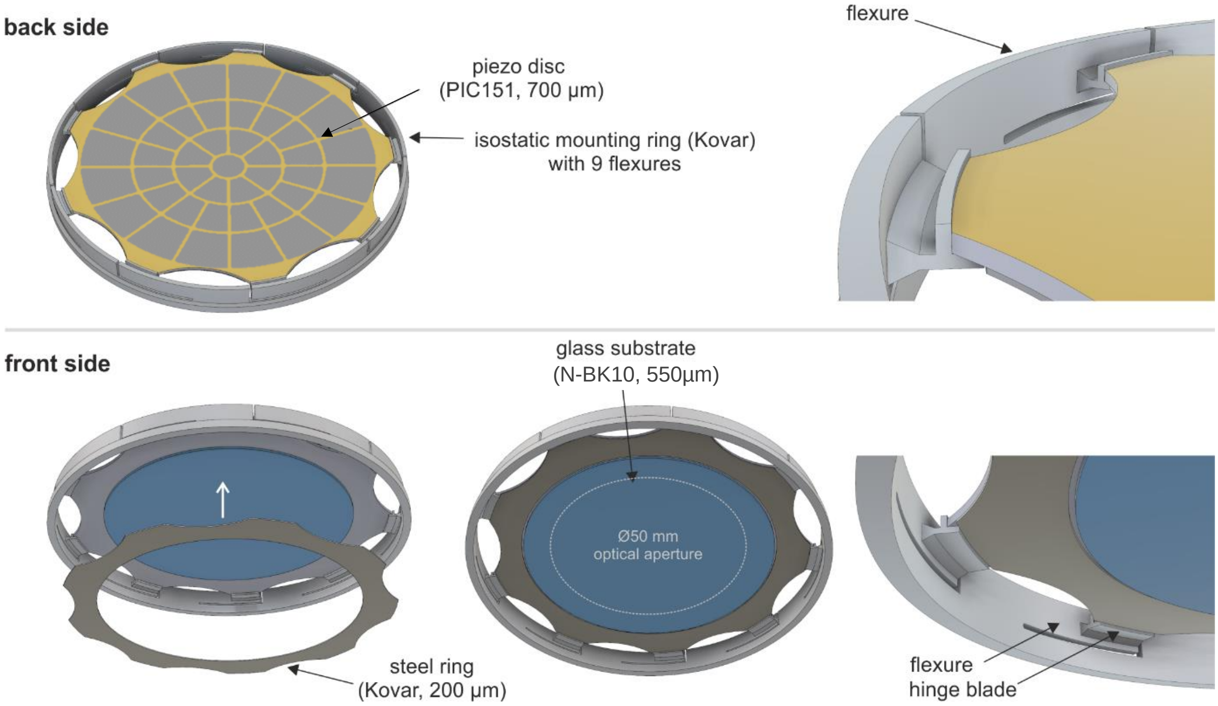

Figure 1 Three-dimensional view of the isostatically mounted unimorph mirror

due to the reverse piezoelectric effect. Different strains of the piezo disc and the glass substrate cause the laminate to deform. The optimum thickness of 550 µm for the glass disc and 700 µm for the piezo-ceramic disc has been assessed via numerical simulations. The actuator design features a 41-electrode keystone pattern.

Twenty-five of the 41 electrodes are located underneath the 50 mm optical aperture and 16 additional electrodes are surrounding the 25 electrodes in order to establish the proper boundary condition for the optical aperture. This numerically optimized electrode pattern (Fig. 2, top left) enables a high-fidelity Zernike reproduction and diffraction limited imaging ($\sigma_{rms} < \lambda/14$). The petal-like shape of the piezo-disc was derived from von Mises stress calculations and connects the disc to a metal mounting ring. The mounting ring features an isostatic design with nine blade flexures. The blade flexures provide high stiffness in the direction perpendicular to the disc and in the azimuthal direction while being soft in the radial direction. The piezo disc is free to expand while at the same time rigid body movement in lateral or axial direction is prohibited. This design copes with CTE mismatch without introducing significant stress to the mirror.

2 PERFORMANCE AND ENVIRONMENTAL COMPLIANCE

Ten deformable mirrors in four design variations using different piezo-electric ceramics were manufactured and optically characterized. Six of these mirrors were vibration and shock tested.
The surfaces of the deformable mirrors were measured using a phase shifting interferometer developed in the former project, which also allows for an in-situ measurement of the mirror surface during the gluing procedure. In the course of this project, the interferometer has been revised for better vibration isolation. Besides improving the optical setup, software was developed using faster FFT algorithms to reduce the sensitivity towards vibration. The achievable Zernike amplitudes of the newly developed isostatic design with a soft PZT ceramic are given in Figure 3. The unimorph mirrors feature Zernike amplitudes of 40 µm tip and tilt (Z1, Z2), 30 µm defocus (Z3), 25 µm astigmatism (Z4, Z5) and 14 µm trefoil (Z9, Z10) over the optical aperture of 50 mm. Three measurements were taken: the mirror performance after the manufacturing process, after the vibration testing, and after the shock testing. Between these measurements, the small deviations can be attributed to the measurement system. The achieved Zernike amplitudes are considerably higher than the requirements that were consolidated in this project.

Environmental tests have been conducted to assess the space compatibility of the deformable mirror. The results of the former project showed that the mirror is able to withstand gamma and proton irradiation and cryogenic temperatures. High laser power handling capability has been verified

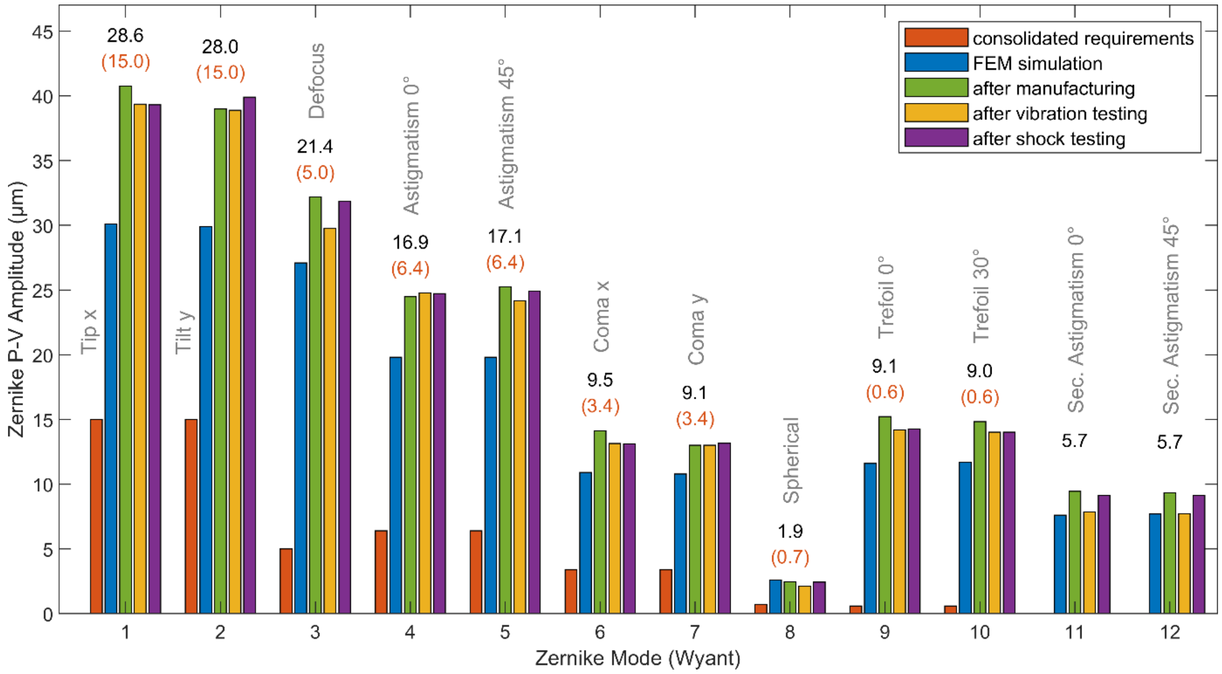

Figure 2 Zernike amplitudes of one of the new isostatic design mirrors with a soft PZT. The mirror fully complies with the consolidated requirements (given in brackets). The performance is constant for measurements taken directly after manufacturing, after vibration testing, and after shock testing.

experimentally with both high average powers and high peak powers. The operation lifetime has been verified since the mirror shows no degradation after approximately 15 million cycles since 2014. The mirror was successfully operated in closed loop with a loop bandwidth of 19 Hz. In open loop operation, a bandwidth of 100 Hz was achieved. The athermal design allows operating the mirror in a temperature range between 100 K and 333 K, which is an important feature for space applications. Additionally, we now verified a non-operational temperature of 353K. We carried out FEM calculations to analyze the mechanical eigenfrequencies of the mirror designs and the stress distribution inside the piezo-ceramic element under vibration load for all investigated piezo materials. A passive resistive and inductive circuit was used to shunt the actuator's electrodes during vibration testing. The dampening effect of this electrical shunting during acoustic excitation tests reduced the vibration amplitude at the first resonance frequency by up to 90 %, depending on the piezo-material and the mirror design.

Vibration tests have been conducted to determine allowable vibration loads. In total, five deformable mirrors were vibration tested with up to 20g sinusoidal vibration and 17.8 gRMS random vibration. The mirrors of the new isostatic design successfully tested at all required sinusoidal and random vibration loads in both vibration directions. Two isostatic mirrors with the same piezo-ceramic were successfully shock tested with a shock response spectrum (SRS) up to 300 g.

3 SUMMARY

An adaptive deformable mirror based on unimorph piezoelectric actuation was refined in order to withstand vibrations and shock loads. The newly developed isostatic mirror design successfully tested at all required sinusoidal (20g) and random vibration (17.8 gRMS) loads in both vibration directions. Additionally, shock tests were successful with a shock response spectrum (SRS) up to 300 g.

The first mechanical eigenfrequency of the re-designed isostatic mirror is twice as high as the first mechanical eigenfrequency of the deformable mirror of the former project, making the isostatic mirror less susceptible towards vibration and shock loads. We are maintaining sufficiently large deformation amplitudes by only altering the shape and mounting of the piezo-ceramic disc. The used soft PZT material was not changed.

The objectives of the reported GSTP activity have been met successfully. Improvements in technology and design have been performed, leading to a current TRL of 5 for the deformable mirror.

The University of Applied Sciences Münster and OHB System AG would like to acknowledge the constructive collaboration amongst all parties throughout the project and that this work was supported by ESA.

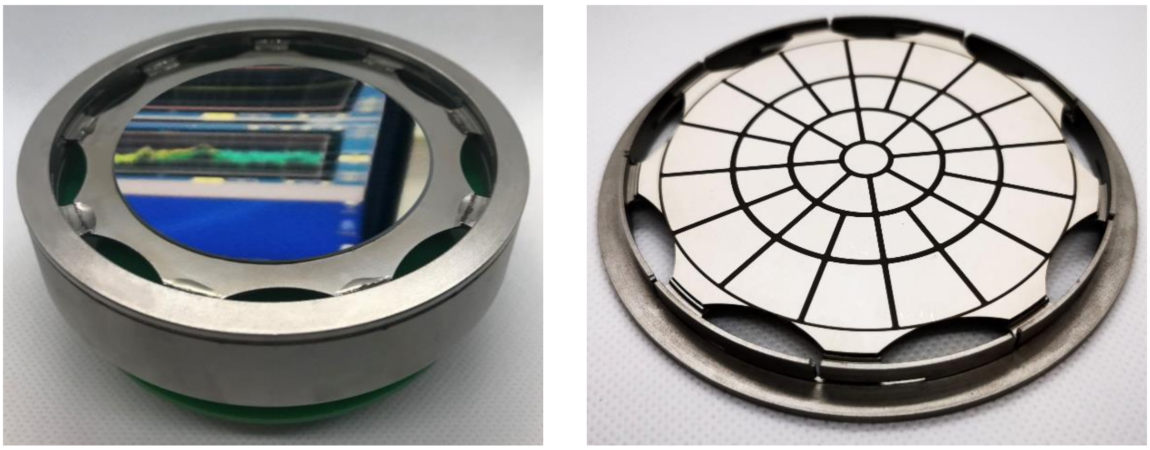

Figure 3 Deformable mirror with the newly developed isostatic mounting, a soft PZT ceramic (700µm) and a dielectrically coated N-BK10 glass substrate (550µm).