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Study of a wide-aperture combined deformable mirror for high-power pulsed phosphate glass lasers

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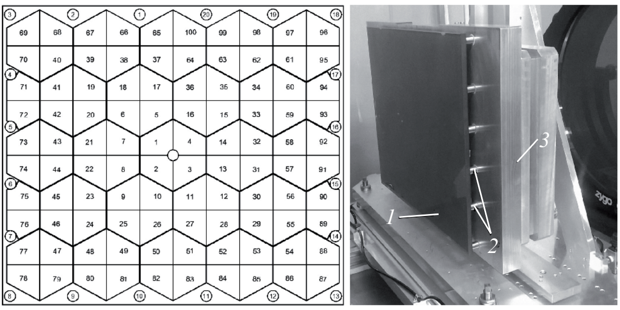
Abstract. **A deformable mirror with the size of 410 × 468 mm controlled by bimorph piezoceramic plates and multilayer piezo stacks is developed. The response functions of individual actuators and the measurements of the flatness of the deformable mirror surface are presented. The study of mirrors with an interferometer and a wavefront sensor has shown that it is possible to improve the surface flatness down to a residual roughness of 0.033 μm (RMS). The possibility of correction of beam aberrations in an ultra-high-power laser using the created bimorph mirror is demonstrated.**

Keywords: *deformable mirror, actuator, wavefront sensor, neodymium glass laser.*

Measurements of the radiation of high-power laser complexes showed that the real aberrations of the output laser beam wavefront have a large-scale character [1]. This means that controlled flexible mirrors can be efficiently used to correct such aberrations. Bimorph deformable mirrors can precisely compensate for large-scale wavefront aberration with the use of a small number of controlled electrodes. At present, bimorph mirrors with the continuous surface up to 150 mm in diameter have been developed and successfully used [2]. However, it is desirable to have even larger mirrors; for example, optical systems with mirrors no smaller than 400 × 400 mm are intended to be applied in modern lasers to study the possibility of producing laser fusion [3, 4]. The absence of wide-aperture bimorph mirror is caused by the problems of mounting a thin but large mirror – membrane with a thickness-to-transverse size ratio of 1/50 and smaller. Vertical mounting of a mirror leads to significant aberrations in its surface caused by stresses at the points of contact of the mirror with the mount. The curvature of the mirror also changes due to gravitation, variations in the environmental temperature and heating by laser radiation.

We developed and fabricated a combined deformable mirror, which includes driving elements of both bimorph and actuator types. The beam aperture of the deformable mirror was 410 × 468 mm. The roughness of the mirror surface after polishing was better than 2 nm (RMS), the surface flatness before assembling it in its mount being better than 1.5 μm. A dielectric coating ensured a reflection coefficient at λ = 1053 nm higher than 99.9 % and a laser damage threshold no lower than 50 J cm^{-2}.



a b

Figure 1. Combined deformable mirror: (a) scheme of arrangement and configuration of electrodes and (b) photograph of the mirror: (*1*) substrate with reflecting coating; (*2*) actuators; (*3*) metal base.

To minimise the initial mirror aberrations caused by mechanical stresses due to mounting, we used piezoelectric actuators, which were positioned along the edge of the metal base and supported the bimorph mirror over the perimeter. The actuator consisted of a housing and a piezo stack with dimensions of 7 × 7 × 18 mm, which could be exposed to mechanical pre-stress (compression). The range of movement of each actuator was from – 8 to + 8 μm at voltages of ± 80 V. Figure 1a presents the configuration and arrangement of 100 bimorph electrodes and 20 actuators on a 10-mm-thick glass substrate. The controlling electrodes were made as one-quarters of hexagonal piezoceramic plates glued to the rear surface of the glass substrate. The amplitude of the mirror surface deformation by the bimorph electrode was from – 8 to +12 μm at the applied voltage from –300 to +500 V. A photograph of the deformable mirror is presented in Fig. 1b. The mirror surface was analysed with a setup using an interferometer with a beam expanding telescope to increase the beam diameter of the diagnostic laser to 610 mm. In addition, a part of radiation was split off to a Shack – Hartmann wavefront sensor to measure the surface shape. A reference surface was a plane mirror with the error of $\lambda/70$ for λ = 0.632 μm (RMS) at the light aperture of 600 mm.

The initial surface flatness error was about 30 μm. After mechanical adjustment by peripheral actuators, we achieved a flatness of 2.5 μm (P – V). Then, after correction in a closed loop with a wavefront sensor using only the actuators, the aberrations were decreased to 1.5 μm (P – V). When the bimorph electrodes were also activated using no more than 10 % of the dynamic range of the control voltage, the flatness

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obtained was equal to 0.16 μm (P−V) and 0.033 μm (RMS). For comparison, we performed direct measurements by using an interferometer, which showed that, at $\lambda = 0.632$ μm, the flatness was 0.280λ (P−V) and 0.05λ (RMS) (Fig. 2), which coincides with the measurements by the wavefront sensor. The resulting surface quality showed a Strehl ratio of 0.86.

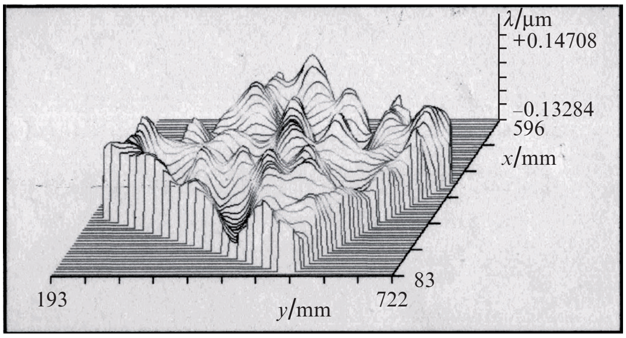

Figure 2. Shape of the corrected surface of the deformable mirror.

Using the experimental response functions of bimorph electrodes, we numerically studied the ability of the deformable mirror to correct the distortions of the wavefront of the output radiation of a Lutch laser facility (RFNC-VNIIEF, Sarov) [5], which were measured by a wavefront sensor. The initial laser beam aberrations as an expansion in 36 Zernike polynomials are shown in Fig. 3a. The amplitudes of these distortions were 17.29 μm (P−V) and 3.82 μm (RMS). After expansion of these aberrations in terms of response functions, we determined the electrode voltages needed for their compensation and calculated the residual wavefront correction error. After correction, the RMS was 0.77 μm (Fig. 3b), which corresponded to the Strehl ratio of 0.81. This should allow one to focus the ultra-high power laser beam in the diffraction limited area, and, therefore, this deformable mirror could be used in the new Russian megajoule laser facility being developed at the RFNC-VNIIEF. Today, the presented wavefront corrector is already installed in an LFEX laser complex (Japan), which demonstrated a record-high output power [6].

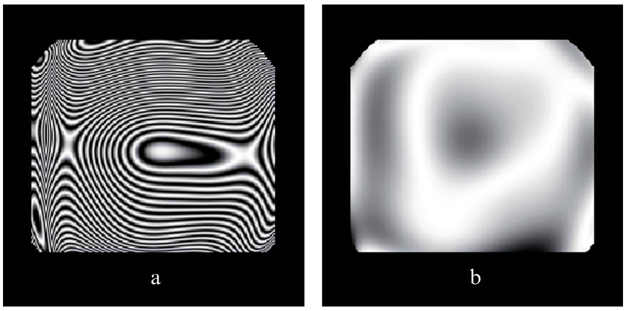

Figure 3. Distortions of the output radiation wavefront (a) before and (b) after correction by the deformable mirror.

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