Large deformable mirrors for beam control of high brightness lasers

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ABSTRACT

Adaptive Optics is now a standard feature to control the laser beam quality of the high power lasers facilities. The development of the next generation of high power and high brightness laser facilities comes along with the increase of the energy of the laser pulses. In these lasers, the size of the optical elements used at the end of the chain must be increased in order to withstand the higher energy of the laser pulses. Laser adaptive optics systems are based on the use of deformable mirrors and are usually located at the end of the laser chain. Therefore, along with the other optics, the size of the deformable mirror must be increased in order to withstand the energy of the laser.

Mechanical deformable mirror technology is compatible with all the standard high power dielectric coatings and is easily scalable. Large mechanical deformable mirrors able to withstand high pulse energies can be manufactured without technological obstacle. We present characterization and **beam shaping** results obtained with two large mechanical deformable mirrors. One mirror has a 180mm circular clear aperture. The other is an **elliptical** deformable mirror with 270 x 190mm clear aperture and is used as a fold mirror at 45° incidence. These large deformable mirrors can withstand pulse energies around 10 kilojoules for chirped pulses. They are compatible with the needs of beam shaping and **beam control** of the next generation of high power and high brightness laser facilities.

Keywords: Adaptive optics, deformable mirror, wavefront sensing, beam shaping, beam control

1. MECHANICAL DEFORMABLE MIRRORS COMPATIBILITY WITH HIGH POWER LASER PULSES

The technology of mechanical deformable mirror is based on mechanical actuators which apply a force on the back of the deformable mirror membrane. Macroscopic displacement of mechanical parts inside the actuator modifies the force applied to the back of the mirror, which modifies on a nanometric scale the shape of the reflective surface. This is how macroscopic part displacement is converted into nanometric shape control. The mechanical actuators that are used are about the size of a pen (Fig.1.). They are attached to the back of the deformable mirror. Since they are physically independent parts, they can be positioned where needed on the back of the deformable mirror. This property makes mechanical deformable mirror technology scalable. For instance, one can easily increase the 2D spacing between actuators to make a larger deformable mirror (Fig.2.). Or one can increase the spacing in only one direction to make elliptical deformable mirrors.

Another aspect of the technology is its compatibility with state of the art high power dielectric coatings from standard manufacturers. These dielectric coatings can induce very large stress and deformation to the thin substrate of the mirror. Mechanical mirrors have extremely large correction amplitudes. For instance, they can generate more than 100µm of curvature or astigmatism. These high values are of course much larger than needed to correct laser wavefront aberrations, but they allow compensating the substrate deformations caused by high power dielectric coatings.

The high power dielectric coatings together with large reflective surface allow using mechanical deformable mirrors with very high energy laser pulses.

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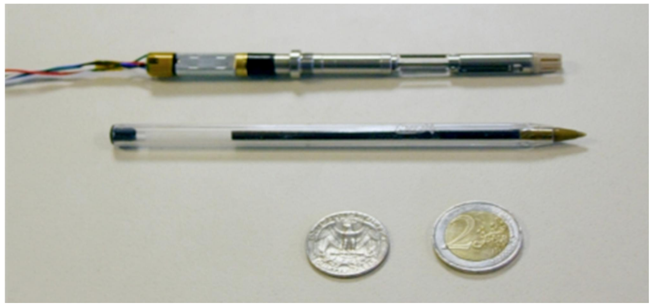

Figure 1. A single mechanical actuator is about the size of a pen.

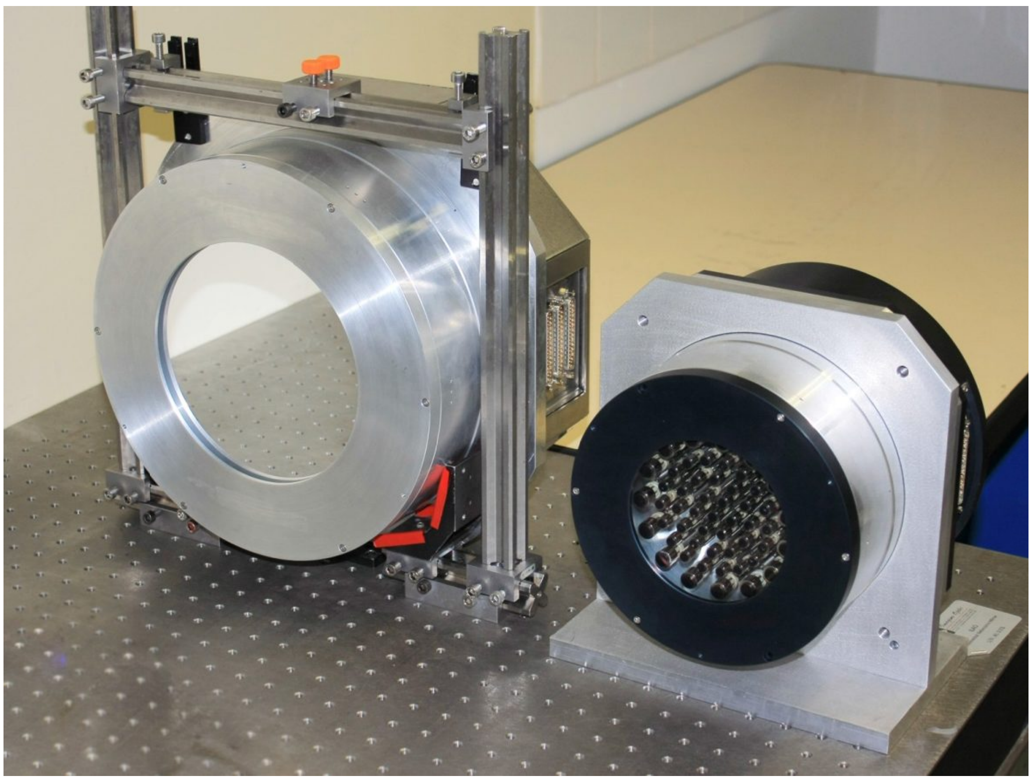

Figure 2. At right, a mechanical deformable mirror with high power dielectric coating. Beam correction diameter is up to 95mm, aperture is 110mm. At left, a mechanical deformable mirror for use in vacuum. Beam correction diameter is up to 180mm, aperture is 200mm.

Some features have been developed specifically for high power laser application. For instance, it is possible to remove and to replace rapidly the reflective surface of the deformable mirror in case of laser induced damage to the reflective surface.

For high power laser applications, the deformable mirror is usually not controlled during high power shots to avoid any shape modification which could result in important modification of the location of focused spot or in hot spots that could damage some parts of the laser installation or expensive optics like gratings. Stability of the wavefront correction is therefore critical for the focal spot correction quality. The technology of mechanical deformable mirrors is intrinsically extremely stable: electrical power is only needed to move the macroscopic parts inside the actuators. Then, it is not necessary to hold a voltage or current to the actuator to maintain the force applied to the mirror. Mirror shape remains perfectly stable over time if power is turned off or if the controller is unplugged. Correction quality is maintained without having an adaptive optics close loop running continuously and deformable mirror becomes a perfectly passive component. This also makes the mirror perfectly insensitive to electrostatic discharge or perturbation as these never carry the power needed to move the mechanical parts inside the actuators.

2. EXAMPLE OF IMPLEMENTATION OF A DEFORMABLE MIRROR ON AN EXISTING LASER CHAIN

Implementing an adaptive optics close loop on an existing laser chain is usually not an easy task. As mechanical deformable mirror are scalable, it is possible to manufacture elliptical deformable mirror. A standard fold mirror can so be replaced by an elliptical deformable mirror, which avoids having to set up of a complex and cumbersome optical path as is necessary with standard circular deformable mirrors in order to keep an incidence angle of a few degrees (Fig.3.).

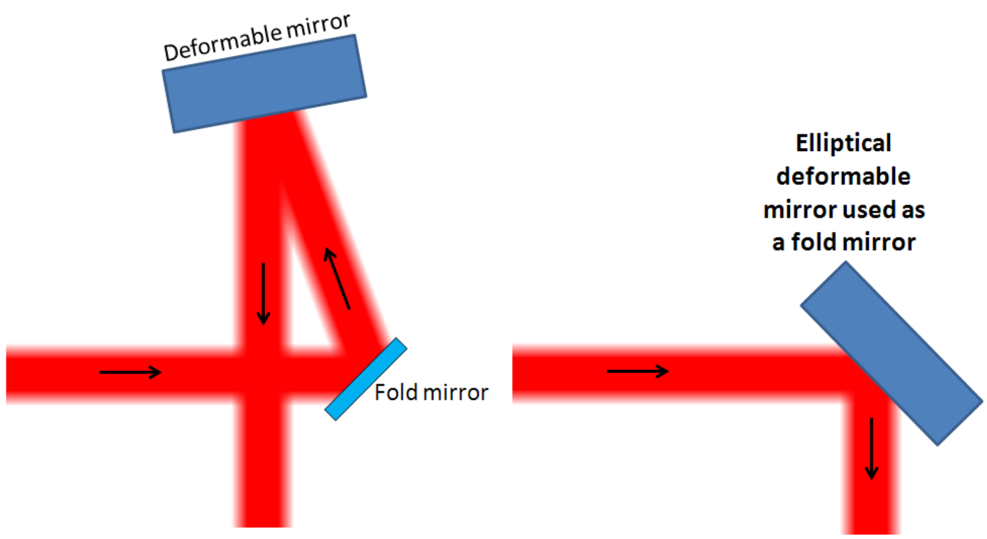

Figure 3. At left, complex optical path with a standard circular deformable mirror. At right, simple optical path with an elliptical deformable mirror used as a fold mirror.

The deformable mirror presented is used in an ultrafast, high power Ti:Sapph laser facility [1]. It is located in vacuum just after the compressor. It can correct beam up to 95mm diameter. It is coated with a high power dielectric from standard manufacturer chosen by the customer. This dielectric coating is specified to hold more 8J/cm² for the chirped pulse before compressor. Such a mirror is therefore capable of withstanding pulse energies of 500J. The actual fluence for the compressed pulses is much lower because of the lower damage threshold of the compressor gratings. The aperture size is 190mm x 130mm (Fig.4.).

Figure 4. The elliptical mechanical deformable mirror with high power dielectric coating.

3. CHARACTERIZATION RESULTS

The actuators of the deformable are located so that the geometry "seen" by the beam at 45° incidence is circular. Therefore, the implementation and performance are similar to a standard circular deformable mirror. The optical quality of mechanical deformable mirrors is excellent. The active flat quality of the elliptical deformable mirror has been measured at **8nm RMS on the wavefront** (Fig.5.), which is typical of what is obtained with circular mechanical deformable mirrors. No actuator footprint is visible on the corrected wavefront.

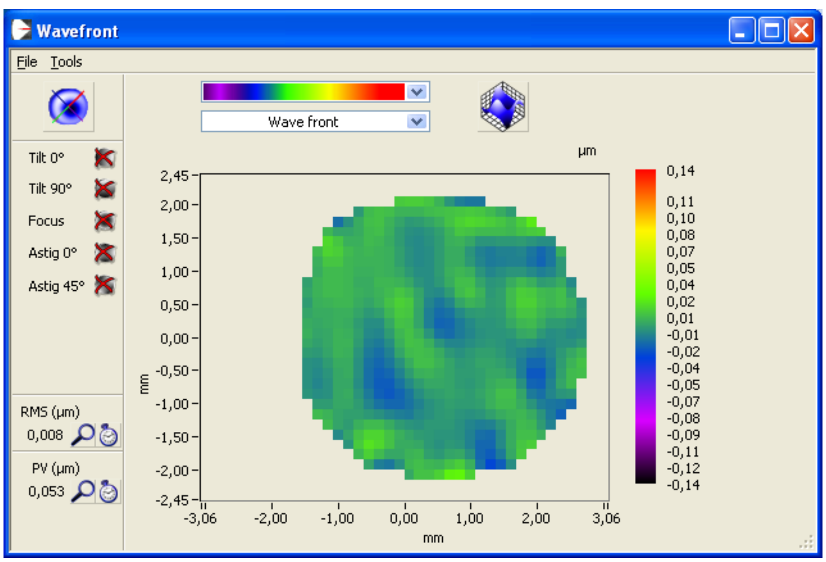

Fig. 5. Active flat quality obtained in laboratory with controlled air turbulence is 8nm RMS on the wavefront. The pupil is circular because the elliptical deformable mirror is used at 45° incidence angle.

Mechanical deformable mirrors are capable of generating very large wavefront deformations while maintaining excellent optical quality. Fig.6. shows a deformation of amplitude larger than 10µm PtV on the wavefront, made of a complex set of aberrations containing aberrations up to 5th order astigmatism, and including 1µm of spherical aberrations. Such a deformation is made with a precision of 12nm RMS

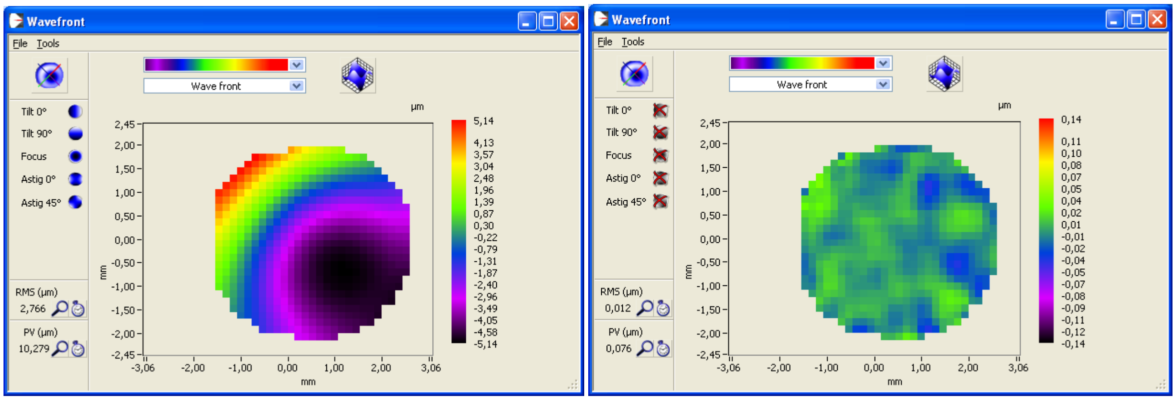

Fig. 6. Large deformations (>10µm PtV, right) on the deformable mirror still allow excellent correction quality (residual 12nm RMS on the wavefront, left).

This excellent optical quality allows avoiding the appearance of hot spots in the intensity profile of the laser after propagation. Indeed, small wavefront errors have almost no effect on the focal spot quality (25nm RMS on the wavefront correspond to Strehl ration of the focused spot of 0.95). However, according to their spatial frequency, they can show up as dramatic hotspots in the beam [2]. With high power laser, such hot spots can yield to damage of the optics located downstream of the deformable mirror. It is therefore important to have an optical quality that does not induce high spatial frequencies. The propagated intensity with a mechanical deformable mirror has been calculated with Miro software. Simulations (Fig.7.) show that the effect on the intensity profile after 20m of propagation is only a few percent modulation.

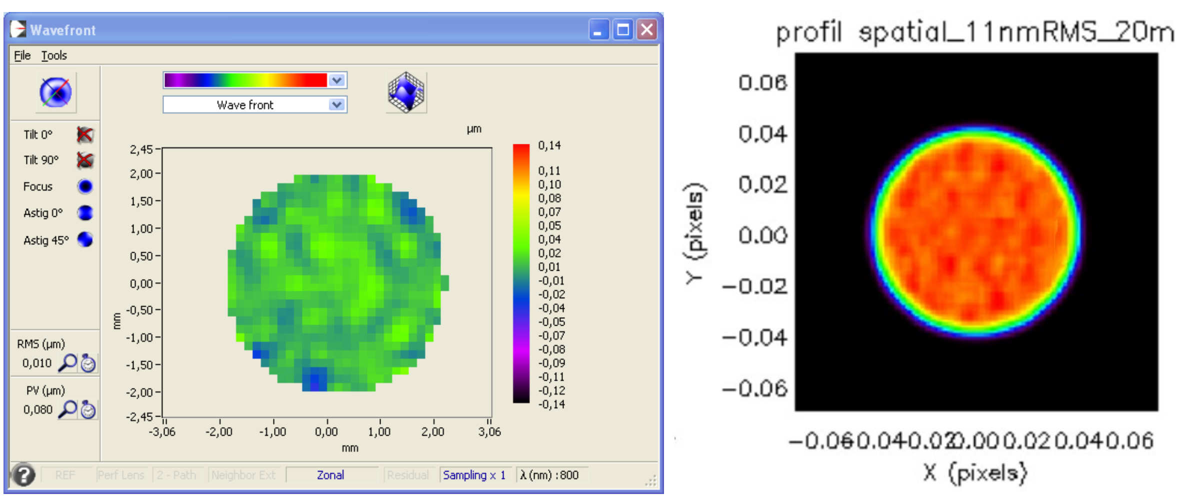

Fig. 7. Left, residual wavefront after 21µm of deformation on the mechanical deformable mirror is 10nm RMS on the wavefront. Right: after 20m of free space propagation, the intensity profile of the beam does not show any hot spot (courtesy of Jiping Zou, LULI).

4. CONCLUSION

A larger deformable mirror is being manufactured. This mirror is also elliptical and can correct beams up to 180mm diameter. The aperture of the deformable mirror is 270x190mm.The mirror will be located just before compressor. It is equipped with a high power dielectric coating capable of withstanding without damage chirped pulses up to 20J/cm². This mirror will be able to withstand pulse energies higher than 5kJ.

High power coatings can withstand even higher energies in a different configuration. For instance, with nanosecond pulses at 1064nm, coatings are capable of holding more than 50J/cm². Mechanical deformable mirror can also be made larger. For instance, a circular mechanical deformable mirror capable of correcting a 270mm diameter beam used with a nanosecond, 1064nm laser will be capable of withstanding pulses energies of several tens of kJ.

With their characteristics, large mechanical deformable mirrors coated with state of the art high power coatings offer performance compatible with the needs of beam shaping and beam control of the next generation of high power and high brightness laser facilities.

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