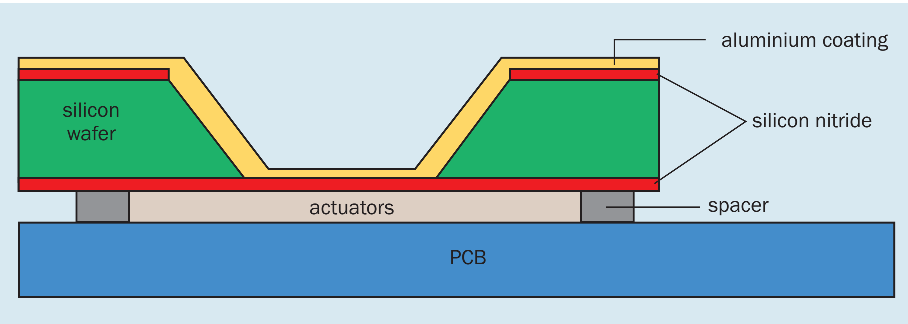
Deformable mirrors flex low-cost potential

Adaptive optics are seen as an expensive luxury that only professional astronomers can afford. However, as **Michael Hatcher** reports, one European project is intent on bringing their capabilities to many other applications.

University of Applied Science Münster, Photonics Laboratory

1. Power to the people: the flexible membrane mirror handles up to 500 W of continuous-wave YAG power.



2. The micromachined membrane deformable mirror (MMDM) consists of a thin (500 nm) silicon nitride membrane, which is coated with a reflective metal. It is fixed to a silicon frame and suspended above an array of 37 electrostatic actuators. The actuators are arranged either linearly or hexagonally. A voltage applied to the actuators deforms the mirror in its local region so that it reflects incident light in a different direction. The applied voltages can be quickly switched to perform fast aberration correction.

Adaptive optics is something of an expensive luxury. So far, astronomers have been the main beneficiaries of the technique and there has been little penetration of other niche areas or mass markets. However, whereas the cost of a large astronomical system typically runs into many millions of dollars, the biggest block to the application of adaptive optics in more mainstream areas has been the lack of small, high-quality, inexpensive adaptive elements.

Finding a low-cost solution in adaptive optics has been the main thrust of an EU project that ends this month. Micro-optical silicon systems (MOSIS) was charged with making affordable adaptive optics in the shape of deformable mirrors and with finding novel applications and potential markets for them (*OLE* July 1999 p33).

Gleb Vdovin is at the hub of the MOSIS project. He and his team at Delft University of Technology in the Netherlands have successfully developed low-cost micromachined membrane deformable mirrors (MMDMs, figure 2), while other project partners have looked to develop a range of applications for the devices. Vdovin set up Okotech, a company based in Delft, to make and sell the MMDMs. Okotech has since mutated into Flexible Optical, which is looking to move its attention towards more commercial applications as well as addressing the scientific market.

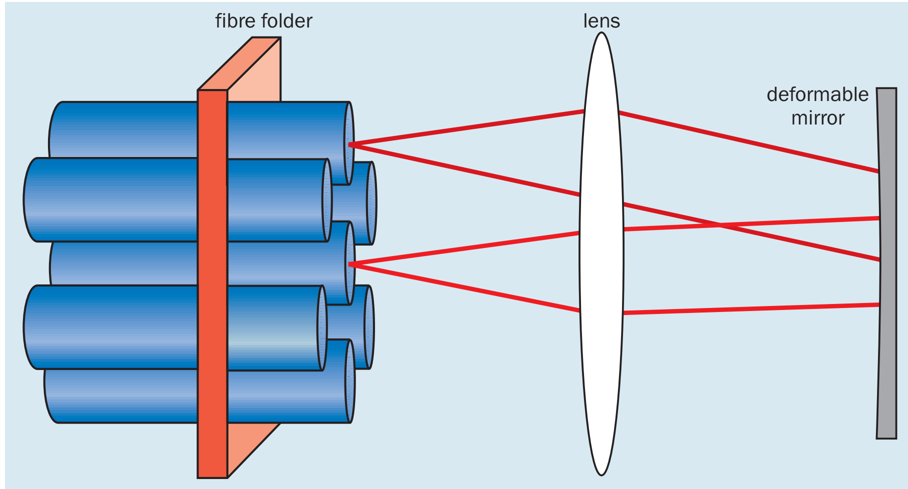
Three technologies in one

The key to making affordable adaptive optics was to use bulk silicon micromachining to make the mirrors. Vdovin said: “Essentially, by combining optical, electronic and mechanical engineering in bulk silicon micromachining, we have replaced three technologies with one.” The resulting devices are, in terms of optical quality, at least as good as any other adaptive technology, according to Vdovin. Their strength, and drawback, is their small size. This sets them apart from existing adaptive mirrors but precludes their use in large telescopes – the biggest current market in adaptive optics.

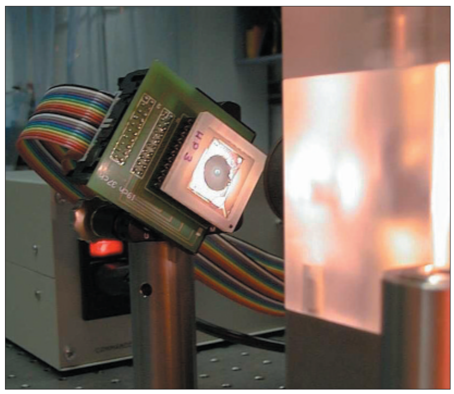
Applications investigated under MOSIS include beam shaping to improve the beam quality of high-power lasers, ultrashort pulse compression, retinal imaging and vision correction.

At the University of Applied Science in Münster, Germany, Ulrich Wittrock has been using an MMDM in a master-oscillator power amplifier system (figures 1 & 4). “We wanted to correct small fluctuations in thermal lensing and higher-order thermo-optical aberrations [that degrade beam quality],” said Wittrock.

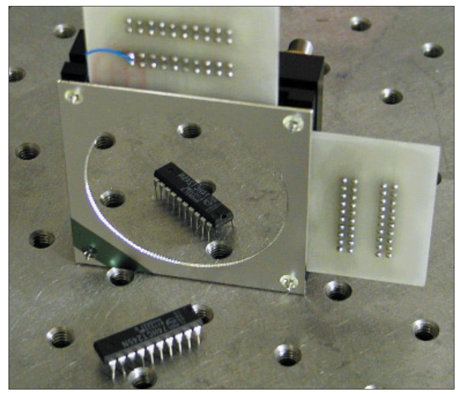
The MMDM both analyses and corrects these aberrations caused by the amplifier ▷



3. Pick a fibre, any fibre: in the Neuchâtel set-up, signals entering down the central input fibre are rerouted down one of the output fibres by a combination of the lens and the deformable mirror.



4. Close-up of the MMDM in a master oscillator power amplifier to correct thermal fluctuations.



5. Flexible friend: this mirror has 37 actuators under a flexible membrane to correct optical aberrations.

rods. The result should be a multitude of benefits for industrial laser users. Wittrock explained: "The better beam quality enables the use of smaller, lighter and cheaper focusing optics and smaller diameter fibres. This, in turn, gives higher cutting speeds, a larger stand-off distance between the focusing optics and the workpiece, and a larger depth of focus."

Immediate applications

The MMDM operates at impressive power levels, says Wittrock. "In our tests, the MMDM withstood 55 W YAG laser power focused to a 0.22 mm diameter spot. That corresponds to 144 kW/cm^2 on the mirror surface. We have operated at over 500 W in continuous-wave mode and I suspect that the maximum possible average power could be several kilowatts," he said.

Despite these figures, Wittrock believes that commercial interest in such industrial high-power applications is still several years in the future. He said: "In my opinion, the more immediate applications of MMDMs will be diode laser beam shaping and temporal pulse shaping in ultrafast lasers. There are also many imaging applications where low-cost MMDMs can significantly improve optical performance."

One such application is in retinal scanning (p29). Vdovin says that, because the size of the MMDMs is similar to that of the human eye, they are ideal for this use – being of a similar size means that the aberrations are also of a similar magnitude.

At the Universidad de Murcia in Spain, Pablo Artal, a pioneer in adaptive optics and particularly its use in human vision, is using the MMDMs to develop so-called "super-vision" systems to improve human visual performance beyond the natural limit. Having demonstrated this with a 1 m^2 breadboard set-up, he is now adapting the system to make a pair of spectacles – this being exactly the type of application where the small size and weight of Vdovin's devices are so convenient.

Artal's closed-loop set-up could also correct vision in patients with unusual corneal pathologies that cannot be corrected with conventional optics, as a visual simulator to test the effects of ophthalmic devices or refractive surgery, and for the early detection of retinal diseases.

Artal believes that the low cost of the MMDMs means that practically any lab can afford to buy them, and he says that they

Who's who: MOSIS and applications of MMDMs

TU Delft	The Netherlands	deformable mirror fabrication
LMT Berlin	Germany	high-reflectance coatings
University of Edinburgh	UK	device integration
Imperial College London	UK	novel curvature wavefront sensor
IMT Neuchâtel	Switzerland	adaptive optical fibre coupling
FCSH Müenster	Germany	high-power laser applications
NIST	US	transform-limited 15 fs pulses
		ten-fold increase in soft X-ray intensity
Universidad de Murcia	Spain	"super-normal" vision spectacles
ITO Stuttgart	Germany	automated fibre coupling

are easy to control with simple electronics and a fast response. He says that the MMDMs proved more successful than previous efforts with spatial light modulators.

Evident drawbacks

Some drawbacks are evident though, according to Artal. He points out that the mirrors can be fragile, something that must be addressed for some "real" applications. In addition, only a fraction of the mirror can be used and some aberration modes cannot be reproduced.

Another MOSIS partner, René Dändliker of the Institute of Microtechnology at IMT Neuchâtel in Switzerland, has led the development of an optical fibre switch based on an MMDM. Light from a single input fibre is redirected down one of an array of output fibres using a lens and the MMDM (figure 3).

Moving the lens switches the optical output to a different fibre and the MMDM corrects any aberrations that moving the lens induces. For example, the switch could be used as a router in metropolitan networks. According to Frédéric Gonté and Yves-Alain Peter of IMT, who have developed and built the prototype, the MMDM has enabled them to surpass their initial goals. "The mirror allowed us to demonstrate a fibre switch even more massive than expected," said Gonté.

In the prototype device, the fibre pitch is 25 µm and a 37-electrode array MMDM is used. Gonté compared a standard, flat mirror with the MMDM. He found that the MMDM increased the efficiency of the coupling from 50% to 73% (the maximum theoretical efficiency is only 80%.

Gonté adds that a similar system with a two-dimensional hexagonal fibre bundle with a 13 µm pitch could be extended in two dimensions to build a switch containing more than 1000 addressable fibres. Industry seems to like the idea. "We have several industrial interests for the fibre switch and for dynamic coupling of doped fibre," said Gonté.

MOSIS has made these applications possible at an affordable price – the basic cost of

Bringing adaptive optics to back-garden stargazers, as well as multimillion dollar observatories, could prove to be the mainstream breakthrough

a 10 mm aperture MMDM is USD 1000. Frustratingly for Vdovin, the low price of MMDMs compared with conventional adaptive optics systems puts some customers off, because they see the low price as a reflection of low quality. The most popular MMDM is a 15 mm, 37-channel device that costs USD 60 per channel (figure 5). Vdovin says that the generally accepted figure is USD 1000 per channel.

Flexible Optical currently has no direct competition and Vdovin is seeing a steady rather than a spectacular rise in orders. "We've sold over 50 systems and more than 150 MMDMs," he told *OLE*.

A more dramatic increase in sales demands a mainstream application and could come from astronomy – again. The MMDM's size makes it suitable for the adaptive correction of images seen through relatively small telescopes. Although Vdovin points out that collecting a sufficient amount of light through a relatively narrow aperture could be a problem, bringing adaptive optics to back-garden stargazers, as well as multimillion dollar observatories, could prove to be the mainstream breakthrough for MMDMs. □

Further information

OLE December 1999 p42; July 1999 p33; November 1997 p17.