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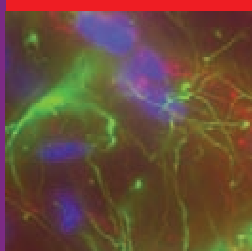
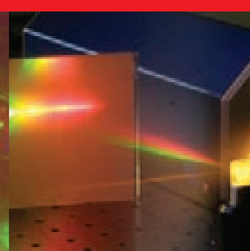
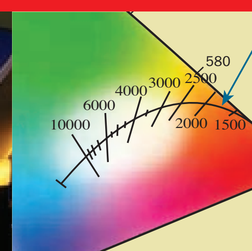
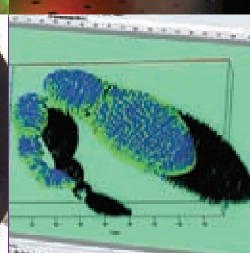
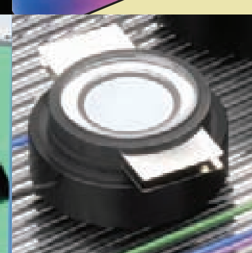
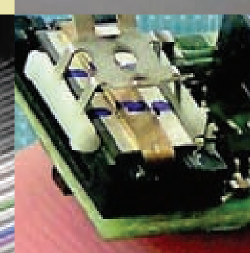
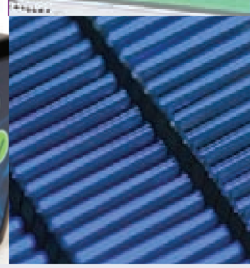
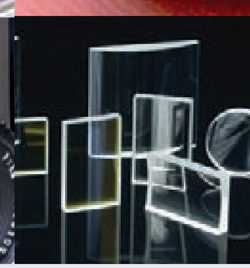
Helping you to choose the perfect photonics product





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EDITORIAL
Editor Jacqueline Hewett
Tel +44 (0)117 930 1194
jacqueline.hewett@iop.org

Reporter Marie Freebody
Tel +44 (0)117 930 1020
marie.freebody@iop.org

Reporter Tim Hayes
Tel +44 (0)117 930 1022
tim.hayes@iop.org

Senior production editor Alison Gardiner
Technical illustrator Alison Tovey

EUROPE/ROW/NORTH AMERICA EAST SALES
Group advertisement manager Rob Fisher
Tel +44 (0)117 930 1260
robert.fisher@iop.org

Advertisement manager Chris Thomas
Tel +44 (0)117 930 1090
chris.thomas@iop.org

Senior sales executive Katrina Davis
Tel +44 (0)117 930 1284
katrina.davis@iop.org

Senior sales executive Matthew Green
Tel +44 (0)117 930 1028
matthew.green@iop.org

NORTH AMERICA WEST SALES
Sales manager Rosemarie Guardino
guardino@ioppubusa.com

IOP Publishing Inc, Suite 929, 150 South Independence Mall West, Philadelphia PA 19106, USA
Tel +1 215 627 0880. Fax +1 215 627 0879

ADVERTISING PRODUCTION
Advertising production coordinator Katie Graham
Tel +44 (0)117 930 1036
katie.graham@iop.org

Advertising production editor Mark Trimnell

CIRCULATION AND MARKETING
Circulation manager Claire Webber
Tel +44 (0)117 930 1165
claire.webber@iop.org

ART DIRECTOR
Andrew Giaquinto

PUBLISHER
Susan Curtis
Tel +44 (0)117 930 1035
susan.curtis@iop.org

OPTICS & LASER EUROPE
Dirac House, Temple Back, Bristol BS1 6BE, UK
Tel +44 (0)117 929 7481
Editorial fax +44 (0)117 925 1942
Advertising fax +44 (0)117 930 1178
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TECHNOLOGY GUIDE 2009

Leader

***OLE*'s annual technology guide is now in its sixth year** and continues to retain its popularity amongst our readers. Each article is written by an industry expert and describes the state of the art in a particular technology area as well as providing answers to frequently asked questions and any simple rules of thumb that make all the difference before approaching a vendor. You will also find discussions of emerging applications and any common misconceptions that cause confusion when buying products.

Every article is written from an independent and impartial standpoint and we strive to make them all as easy to read as possible. So whether you are looking to buy a new product or get up to speed with recent progress in a particular technology, all of the information that you need is at hand.

All the information you need to make an informed purchasing decision is at hand.

As well as this printed edition of the *Technology Guide*, you can download an electronic version as a PDF, a useful file to archive on your computer and have at your fingertips. To download your copy, visit the Buyer's Guide section of our sister website *optics.org* and follow the link to the 2009 Technology Guide on the left hand side of the page: http://optics.org/cws/buyers-guide.

I am sure that you will find the *Technology Guide* a valuable reference covering a variety of today's hottest technology areas. For example, this year's guide brings you up to date on white LEDs and the iterative approach you should take when designing lighting systems, ultrafast fibre lasers producing picosecond and femtosecond pulses, and the key criteria to consider when purchasing adaptive optics.

Other topics include fluorescence microscopy, power meters, UV detectors, nanopositioning systems, spectrometers, high-power laser diodes, CMOS cameras and cylindrical lenses.

Jacqueline Hewett
Editor

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Choosing adaptive optics for precision applications

Knowing how to decide between the various options is a daunting task for anyone considering adaptive optics. **Jérôme Ballesta** and his colleagues from Imagine Optic take some of the mystery out of choosing adaptive optics products for precision applications.

Table 1: Criteria for choosing a wavefront sensor

	Accuracy	Measurement dynamic	Sensibility	Intrinsic resolution	Spectral bandwidth	Acquisition rate
Astronomy	Useful	Useful	Essential	Important	Useful	Essential
Laser beam focusing	Important	Very important	Negligible	Important	Useful	Useful
Microscopy (open loop)	n/a	n/a	n/a	n/a	n/a	n/a
Microscopy (closed loop)	Important	Essential	Essential	Important	Negligible	Useful
Ophthalmology	Important	Essential	Essential	Important	Negligible	Useful

Essential Very important Important Useful Negligible

Table 2: Strengths and weaknesses of wavefront sensor technology

Sensor type	Strengths	Weaknesses
Shack-Hartmann	One-shot measurement Functions in real-time Measures both phase and intensity Wide dynamic range and spectral bandwidth Insensitive to vibration Accuracy and reliability	Large number of pixels needed to create a data point thus reliant on a high-resolution CCD camera
Wavefront curvature sensors	High lateral resolution Insensitive to vibration Speed Wide spectral bandwidth	Only capable of measuring collimated beams Limited dynamic range and bandwidth Limited sensitivity in low-light situations Produces phase map as a function of measured intensity
Shearing interferometers	One-shot measurement Large number of wavefront sampling points Insensitive to vibration	Lateral resolution typically 3–4 times inferior than the number of wavefront sampling points Limited sensitivity in low-light situations.

Adaptive optics has become a hot topic and an industry buzzword over the past few years. What is it? How does it work? The goal of this article is to provide some general information about how to choose the right components for your application.

A typical adaptive optics system is composed of a wavefront measurement device, an active wavefront shaping element, and a command and control software package that processes and relays information between the other components. You will find varying degrees of quality and precision on the market, which is reflected in the range of prices.

The first "real-world" applications of adaptive optics were seen in the 1970s when the US military used the technique for laser beam compensation and improving the quality of satellite imaging. The influx of defence industry capital into this still budding technology enabled it to mature significantly in a short period of time.

The first adaptive optics systems relied solely on deformable mirrors (DMs) as their active component. Because individual applications have widely varying needs with regard to spatial resolution and dynamic range, the first quest in adaptive optics was to increase the density, dynamic range and reactivity of the actuators that controlled the mirror's reflective surface.

As the technology continued to evolve, its growing popularity contributed greatly to reducing the cost of various elements, most notably the active wavefront shaping components. 10 years ago there were only three suppliers of DMs and prices exceeded $1500 (€975) per actuator. Today, there are at least 10 different DM manufacturers that offer varying levels of performance at prices between $50 and $2000 per actuator. A new generation of MEMS-based DMs is available at prices between $50 and $700 per actuator.

In addition to DMs, a second general group of wavefront shaping technologies exists: spatial light modulators (SLMs)

Table 3: Key criteria for choosing active components

	Correction dynamic	Temporal bandwidth	Residual error*	Linearity	Low hysterisis	Pointing stability	Damage threshold
Astronomy	Very important	Essential	Very important	Useful	Useful	Important	Negligible
Laser beam focusing	Essential	Negligible	Essential	Useful	Useful	Useful	Essential
Microscopy (open loop)	Essential	Useful	Very important	Essential	Essential	Essential	Negligible
Microscopy (closed loop)	Essential	Useful	Very important	Useful	Useful	Useful	Negligible
Ophthalmology	Essential	Useful	Very important	Useful	Useful	Useful	Negligible

* measured as the remaining wavefront error when the mirror is in a flat state

Essential · Very important · Important · Useful · Negligible

Table 4: Command and control software

	Influence matrix measurement and command matrix calculation	Wavefront sensor control	Save target wavefront	Security (suspicious events, parasite signals)	Real-time online aberration command	Open loop
Astronomy*	Essential	Very important	Essential	Important	Essential	Important
Laser beam focusing	Essential	Essential	Essential	Essential	Useful	Useful
Microscopy (open loop)	Useful	Useful	Useful	Useful	Useful	Essential
Microscopy (closed loop)	Essential	Essential	Essential	Essential	Essential	Useful
Ophthalmology	Essential	Essential	Essential	Essential	Essential	Useful

* Adaptive optics for astronomy uses software dedicated to this application. These indications are only general guidelines for software functionality.

Essential · Very important · Important · Useful · Negligible that are based on liquid crystal technology. Whereas deformable mirrors use a modifiable reflective surface to reshape the wavefront, an SLM generally uses synthetic holography to correct the wavefront.

The wavefront sensor

The first question that you need to ask yourself is: "will I be working in an open- or closed-loop configuration?". This basic question defines whether you will be using a wavefront sensor (WFS) to measure the incoming light (closed loop) or adjusting your active component manually until you get the desired effect (open loop). We will concentrate on closed-loop systems as they are by far the most widely used.

The first element to consider in your adaptive optics system is the WFS. There are three principal wavefront sensing technologies: Shack-Hartmann, wavefront curvature sensors and shearing interferometers. Thanks to the technology's maturity, the most commonly used WFSs belong to the Shack-Hartmann family. These WFSs focus the incident wavefront into an array of spots on a photoreceptive plate and calculate the local slopes based on each spot's intersection point. Wavefront curvature sensors function in a similar manner to Shack-Hartmann devices, however they measure the relative intensity at fixed points on either side of the focal plane. Shearing interferometers process the fringe patterns formed by several laterally shifted identical wavefronts as they pass through a diffraction grid. Table 1 (p15) illustrates the importance of different criteria when choosing a WFS for adaptive optics while table 2 (p15) shows the strengths and weaknesses of each WFS technology.

All three of these technologies are potential candidates for your closed-loop system, however, keep the following points in mind. Firstly, precision is a primary concern because it determines the quality of the corrected wavefront and, put simply, you cannot correct better than you can measure. Secondly, dynamic range is essential. The sensor must have the ability to measure aberrations with equal or larger amplitudes than the DM is capable of correcting.

Wavefront shaping

The active wavefront shaping component largely determines the overall performance of the adaptive optics loop so the choice between a DM and SLM is dependant on what you want to accomplish. Once you know what you want to do, you must then look at the technical characteristics, strengths and limitations of the different technologies that are available to you, including resolution, stroke (dynamic range), speed, optical quality or damage threshold.

Commercially available SLMs have resolutions that range between 800 × 600 pixels (VGA) up to 1920 × 1080 pixels (HDTV). SLM technology combines high resolution with relatively low cost (due largely to the mass use of LCD technology) with the ability to locally reshape high-spatial frequency aberrations. SLMs are ideal for applications such as low-energy beam shaping, complex optical tweezers and holography.

While excellent tools for the applications mentioned above, several key limitations currently inhibit the use of SLMs in parallel domains where adaptive optics is used to optimize the point spread function (PSF), or to increase the resolution of imaging instruments. These limitations include the fact that SLMs exhibit diffractive behaviour; are more complicated to integrate than DMs; do not have the necessary dynamic range to correct for low spatial frequency aberrations; have a relatively low damage threshold; are dependent on polarization, and are chromatic by nature.

DMs use a continuous reflective surface that is manipulated by actuators to modify the entire wavefront. Some MEMS-based DMs use arrays of densely packed miniature mirrors to mimic the effect of a continuous surface. DM technology has a wider range of use in high-end applications thanks to the fact that it is achromatic by nature and can correct for both high and low spatial frequency aberrations.

The first step in choosing your active component is to analyse the wavefront that you would like to correct or optimize. Knowing some key facts will allow a vendor to assess your situation and propose a suitable system. We strongly recommend using a standard experimental procedure to obtain a complete series of wavefront measurements, the results of which will be matched to individual DM specifications. Here are the key facts that you will need to know:

- Amplitude and spatial frequency of aberrations – will help to define the stroke;
- Temporal bandwidth of aberrations – will define the DM response time;
- Stability requirements of the mirror's shape – users of pulsed sources do not have the same stability needs as users of continuous-wave beams;
- A qualitative assessment of what you want to achieve after applying adaptive optics correction;
- Damage threshold – how much energy does your mirror need to withstand?

Ideally, DM correction specifications should be defined by the device's ability to reproduce Zernike forms (polynomial [geometric] representations of various types of aberrations). It is important to think pragmatically during this process. How perfect does it need to be? What residual, post-correction wavefront error can your application tolerate?

There is more to wavefront correction than the number of actuators or the device's stroke. Other important DM characteristics include dynamic range (capacity to correct for lower and higher spatial frequency aberrations), temporal bandwidth, hysteresis, linearity, damage threshold and optical surface quality. Your sales vendor will take all of the information that you provide from your experimental measurements, pair it up with various DM choices and perform simulations of anticipated outcomes. Table 3 (p16) illustrates the key criteria that are taken into account when choosing active components.

Command and control software

The final piece to the adaptive optics loop is the interface that enables you to control your components, and there is certainly no shortage of command and control software on the market. The important question is: what does my application need? From individual actuator control, component diagnostics and security features, each provider has something to offer. Table 4 (p16) illustrates some of the key features and their usefulness in different applications.

What do I do now that I know what to look for?

Adaptive optics technology has matured enormously over the past decade and there is no doubt that new applications will continue to appear in the very near future. The best advice that we can offer is to find a knowledgeable vendor that you trust to help you through the process of choosing the right equipment for your application.

It is our opinion that a good salesperson will take the time to provide a detailed explanation of the different options on offer and to explain why they believe the option that they are proposing is best suited to your needs. You should never be uneasy about asking for benchmark information or posing probing questions. This is a highly competitive market and customers should play all of their cards. □

Jérôme Ballesta, an expert in wavefront metrology and adaptive optics, is a member of Imagine Optic's team of salespeople. For more information, see www.imagine-optic.com or e-mail contact@imagine-optic.com.