Most people working with lasers today are trying to do something with the light beam, either as the raw beam or, more commonly, modified with optics. Whether it is printing a label on a part, welding a precision joint or repairing a retina, it is important to understand the nature of the laser beam and its performance. Laser beam profiling provides the tools to characterize the laser and know precisely what the beam is doing at the point of the work and if the optics are having the desired effect. Lasers and laser applications come in many varieties, varying in power density, wavelength, depth-of-focus, beam size, pulse duration and myriad other parameters. It is this variety that makes lasers so useful for interacting with and manipulating many different materials and media. But, it is also this variety that adds complexity to the beam profiling process.

**Beam Profiling Technology**

Beam profilers come in many types, each with its own advantages and challenges. The basic types can be narrowed into a couple of categories—array-based or camera-based profilers and mechanical scanning apertures, knife edges and other devices. Today the camera-based and scanning aperture profilers are the leading techniques for most applications. Camera-based systems are generally silicon CCD or CMOS devices, although there are applications using arrays with pyroelectric detectors and microbolometers for detection of longer wavelength lasers. Scanning aperture systems combine a moving slit and single-element photo detector.

Other more specialized instruments, such as the Photon Goniometric Radiometer far field profiler use a scanning pinhole aperture to
measure divergent sources in the far field.

Over the past few years the technology of camera arrays has improved dramatically with reduced pixel sizes, high dynamic range digital interfaces and electronic exposure and gain controls to vastly increase the usefulness of these devices as laser profilers. With the introduction of CMOS cameras, the costs have also come down significantly. Speed and jitter control along with high dynamic range electronics have also improved the performance of the scanning aperture instruments, allowing them to achieve submicron precision for both pointing and beam size measurements. The availability of USB2 and Firewire (IEEE1394) interfaces for both these types of profilers has also increased their ease-of-use and convenience for connecting to both laptop and desktop computers.

Choosing a Profiler

The nature of the lasers to be measured and the requirements for the measurements are the most important criteria for selecting the type and model of profiler best suited to the user’s needs. There are basically four questions that need to be answered to determine the type of laser beam profiler to use:

Wavelength?
The first is what wavelength(s) do you intend to measure. The answer to this question determines the type of detector needed, and what the most cost-effective approach may be. For the UV and visible wavelength range from 250nm up to the very near infrared at around 1100nm the silicon detector has the response to make these measurements. For these wavelengths there are the largest number of cost-effective solutions including CCD and CMOS cameras and silicon detector-equipped scanning aperture systems. Which of these is the best will be determined by the answers to the other three questions. UV beams from 190nm to 250nm can be measured with CCD and CMOS arrays, but the energetic photons at these wavelengths will damage the arrays. For more than occasional use, specialized UV conversion plates, which convert the UV light to visible wavelengths, should be employed. For the near infrared, from 1100 to 1700nm, the choices become less abundant. In the lower end of this range from 1100-1200nm the CCD and CMOS cameras may still work, but above 1200nm InGaAs, pyroelectric or microbolometer arrays become necessary. These are quite expensive; five to ten times the cost of the silicon detectors. Scanning slit systems equipped with germanium detectors are still quite reasonably priced, within a few hundred dollars of their silicon-equipped cousins. At the mid- and far-infrared wavelengths the pyroelectric arrays and scanning slits with pyroelectric detectors provide viable alternatives, again the best approach being determined by the answers to the subsequent questions.
**Beam Size?**
The second question is what beam width or spot size does one wish to measure. This question determines the profiler type. Arrays are limited by the size of their pixels. At the current state-of-the-art pixels are at best around 5µm for silicon arrays, and considerably larger with InGaAs and pyroelectric arrays. This means that a UV-NIR beam should be larger than 50µm in diameter to ensure that enough pixels are lit to make an accurate measurement. InGaAs pixels are at best 30µm, limiting the minimum measurable beam size to around 250µm; pyroelectric array pixels are even larger at 85µm, meaning the beams need to be at least a half a millimeter to yield accurate results. Scanning slit profilers can measure with better than 2% accuracy beams that are four times the slit width or larger, putting the minimum measurable beam sizes at around 4µm without magnification. Those investigators who want to measure their beams directly without additional optics may find this to be an advantage.

**Power?**
The third question is the power of the beam. This determines the need for attenuation, beam splitting, as well as the detector type. Array detectors, especially silicon CCD and CMOS cameras will always need attenuation when measuring lasers. Scanning slit type profilers can measure many beams directly without any attenuation, due to the natural attenuation of the slit itself. The slit only allows light to the detector as the slit passes through the beam, and then it only lets in a fraction of the total light. Arrays allow the entire beam to impact the detector, leading to detector saturation unless the beam is severely attenuated. Lasers of any wavelength with powers above 100mW can be measured with the pyroelectric detector equipped scanning slit profiler. Properly designed, these profilers can measure up to kilowatts of laser power. High power lasers in the hundreds to thousands of watts can also be profiled using the spinning or scanned wire techniques.

**CW or Pulsed?**
The final question is whether the laser is continuous wave (CW) or pulsed. Lasers that operate pulsed at a repetition rate of less than 1-2kHz can only be profiled with an array. Scanning apertures simply cannot make these measurements effectively. CW and lasers with repetition rates above 2kHz can be measured with scanning slits, provided the combination of the repetition rate and the beam size are sufficient to provide enough laser pulses during the transit time of the slits through the beam to reconstruct a good profile. Pulsed beams have other considerations, particularly those with ultra short pulses, concerning power levels and pulse energy damage thresholds.

**A Few More Questions**

Besides these four questions about the physical nature of the laser to be measured, there are a few more that need to be asked: How and where a profiler is to be used is also an important consideration in the equation. Camera arrays provide a true two dimensional image of the beam and will show fine structure and hot spots, which a slit may integrate.
out. Slit based profilers will generally provide a more accurate beam size measurement and can measure very small beams directly. Accurate collimation or focus control requires the highest beam size accuracy. Checking the laser for hot spots, uniformity or beam shape may dictate that the 2d profile is more important than the absolute size measurement accuracy. For a profiler to be used on a factory floor for a manufacturing step, ease-of-use, high throughput, and reproducibility become paramount. In this case the profiler requiring the least “fiddling” is generally the best fit. For any process that uses or works with CW or high frequency pulsed lasers the scanning slit will have the advantage of measuring the beam directly, even at its focus point, without additional attenuation optics. The dynamic range of these systems is also broad enough to measure both the focused and the unfocused beam without changing the level of attenuation.

Camera arrays, on the other hand, may not be able to handle both levels of power density without adjustment. This means that for applications where the beam needs to be brought into focus or measured in various points along its propagation, such as with the measurement of $M^2$ or focusing an optical system, the slit profiler will tend to be much more convenient.

![Fig. 3—NanoModeScan M^2 Measurement System](image)

**Profiling Misconceptions**

People who are new to the idea of profiling are often looking for a one-size-fits-all profiler. Although one profiler may be able to measure several different lasers, a truly universal solution simply does not exist. With all the various wavelengths, beam sizes, power levels it is impossible to make one instrument to do it all. Even the optics—lenses, attenuators, etc.—must have antireflective coatings that are specific to the wavelengths of use. The art of attenuation can also be very tricky. It is possible to introduce error into the measurement simply by using the wrong type of attenuators. For those interested in further information on these topics, please visit our extensive library of application notes at [www.photon-inc.com](http://www.photon-inc.com).