Beam Profiling

A Brief Review of Best Practices

INTRODUCTION

Currently, lasers that vary widely in light wavelengths and beam powers are available for many scientific, industrial, and medical applications. The laser light wavelengths employed in these applications span the spectral range, from nanometer (nm) wavelengths in the ultraviolet (UV) region of the spectrum (157 nm to 364 nm) to terahertz wavelengths in the far-infrared (FIR, 15 μm to 1 mm) region. Scientific spectroscopic applications such as Raman and LIBD spectroscopy, for example, require excitation lasers with wavelengths ranging from UV/Visible and near-infrared (NIR) to the far-infrared (FIR). Industrial applications range from the use of semiconductor lasers for communications and computing purposes through lasers for optical ranging and sensing to the high-power lasers employed in cutting, welding and drilling operations. Increasingly, lasers are finding application in important medical areas such as photo-refractive keratotomy (PRK) and the treatment of skin disorders.

Whatever the application, it is critical that the properties of the laser light beam are both precisely known and optimized. As well, long term repeatability of the laser beam properties is critical to success in most applications. The measurement of laser light beam properties is accomplished with the use of laser beam profilers. This note describes the main beam profiler technology in use today and best practices that relate the optimal beam profiler configuration and laser beam properties.

Beam Profilers

Digital Cameras

Digital camera profilers (Figure 1) have a sensing element (the imager or detector) that consists of a CCD or CMOS pixel array with a fixed number of pixels in the X and Y direction. Each pixel contains a semiconductor-based photosensor made from a photoconductive element such as silicon, germanium or InGaAs; the choice of semiconductor depends on the laser light wavelength (see below). Integration of the signals from the pixels in the array provides full two-dimensional characterizational data for the laser beam cross-section, as shown in

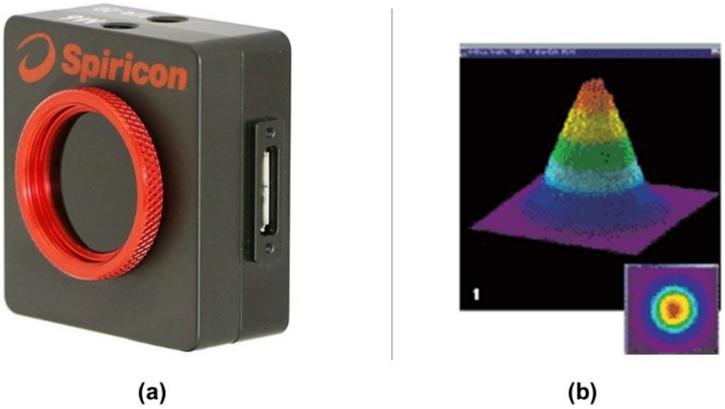


Figure 1. (a) A typical CCD array camera beam profiler; (b) representative beam profile.

Figure 1(b). The variation in the pixel-to-pixel spacing (pixel pitch accuracy) in these sensors is on the Ångstrom scale (1 Ångstrom = 1 × 10^{-10} m), making variations in the pixel-to-pixel spacing an inconsequential consideration in beam profiling. The optimal choice for a camera profiler in each application depends on the physical properties of the laser beam and on the characteristics of ancillary system components. Different imager configurations will give the best results under different combinations of the manner of use, the laser wavelength and certain other conditions. The cameras normally require beam attenuation to avoid saturation or even damage to the sensing elements.

Laser Beam Properties – Beam Profiler Considerations

Four inherent properties of laser beams must be considered when choosing a beam profiler: wavelength, whether the beam is continuous or pulsed, power, and spot size.

Laser Light Wavelengths

As noted in the Introduction, lasers can produce coherent light with a broad range of wavelengths, ranging from the ultraviolet (157 nm) to the far infrared (1+ mm). Beam profilers require different types of laser light detectors or imagers, depending on the wavelength of the beam. These detectors can be configured as either single elements or as arrays of pixels with different pixel sizes and spacings. The choice of configuration depends on the accuracy, resolution and cost requirements of a given application.

Table 1. Wavelength range and usable types of detector.

Wavelength Range	Wavelengths	Usable Detector Type
Extreme UV	13 nm – 190 nm	Pyroelectric
UV	190 nm – 350 nm	Silicon, Pyroelectric
Visible	355 nm – 700 nm	Silicon
Near – IR	700 nm – 900 nm	Silicon, Germanium
	0.9 µm – 1.06 µm	Silicon, InGaAs, Germanium
	1.06 µm – 1.1 µm	Silicon, InGaAs, Germanium, Pyroelectric
	1.1 µm – 1.44 µm	InGaAs, Germanium, Pyroelectric
	1.44 µm – 1.605 µm	Phosphor-Coated Silicon, InGaAs, Germanium, Pyroelectric
	1.605 µm – 1.7 µm	InGaAs, Germanium, Pyroelectric
	1.7 µm – 1.8 µm	Germanium, Pyroelectric
Mid – IR	1.8 µm -15 µm	Pyroelectric
Far – IR	0.015 mm – 3 mm	Pyroelectric

Broadly, detectors can be classified as either thermal detectors or photonic detectors. Thermal detectors use the pyroelectric effect to convert laser-induced heating of materials such as $LiTaO_3$ into an electric signal. Semiconductors commonly used in photodiode detectors include silicon, germanium, and compound semiconductors such InGaAs (Table 1). The detectors in laser beam profilers can be semiconductor photodiode, CCD, or CMOS devices configured as single elements or multiplexed arrays of elements.

CW vs. Pulsed Beams

Lasers produce coherent light as either continuous (CW) or pulsed light beams that can be profiled using either single element or multiplexed array cameras. Pulsed beams may require the use of an optical trigger to synchronize the camera with the laser and achieve a stable beam profile. An optical trigger is a sensor that detects the pulsed laser light and generates an electrical output to the camera to trigger data capture. The optical camera trigger uses an optical sensor that detects pulsed light sources and generates outputs to trigger a camera. The front aperture of the optical trigger must be directed at a light source that provides the necessary properties for trigger activation. (e.g. a laser flash lamp, a pick-off source from the main laser beam, or similar). Some care must be taken with this mode of operation since optical trigger mode will not produce the best image quality. When in the triggered capture mode, the camera is automatically synchronized with the pulse rate of the laser and will only start to expose and transmit a frame of data when the trigger pulse is sent from the optical trigger to the camera.

Average Beam Power Measurements

Different lasers deliver light at different power levels and it is important to know, in advance, the average power of the light impinging on the detector/imager in a beam profiler. Note that, with pulsed lasers, it is important to distinguish between the average power and peak power. Figure 2 shows a simple diagram that can help in understanding the difference between these two power measurements. Beam profiler datasheets always consider power as average power.

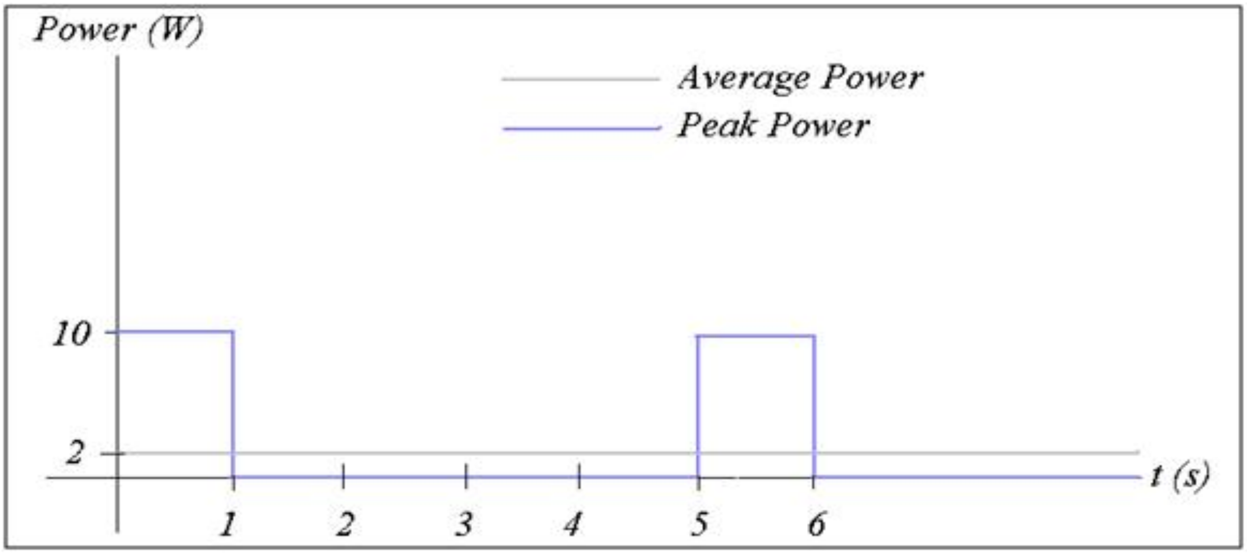


Figure 2. Average vs. peak power. In this case, the peak power is 10 W, the duty cycle is 20% and the average power is 2 W.

Normally, laser beams are characterized by placing the beam profiler at the focal point of the beam and performing the measurement. CCD and CMOS camera beam profilers almost always require some degree of attenuation of the laser beam since the full laser beam impinges on the detector arrays or elements in the camera and this will saturate or damage the detector in most instances. Attenuation, when needed, is normally achieved using either a beam splitter or additional filters (see below).

Beam/Spot Size

The active sensing area needed for the detector/imager in a beam profiler is determined by the size of the collimated beam and the focus spot. Silicon-based arrayed cameras (Figure 1) are suitable for profiling both CW and pulsed light sources having wavelengths between 190 and 1100nm and beam diameters between 40μm and 5.3mm.

Note that spot size must span at least a 10 pixel spacing for the software to calculate the beam profile accurately. The minimum spot size of the laser must be at least 600 μm in a phosphor-coated camera, owing to the scattering of the laser light in the phosphor layer.

Attenuation

The term attenuation refers to the reduction of the energy intensity of a signal, in our case the laser beam. Depending on the laser light source and its end application, the average or peak power of the laser beam may be anywhere from picowatts to multiple kilowatts. Accurate profile measurements of such beams using camera array beam profilers requires attenuation of the laser signal since camera array detectors can only take intensities at or below the milliwatt range to avoid saturation. The degree of attenuation required for beam profiling an application depends on the type of profiler in use and the robustness of its detector. Attenuators (e.g. Figure 3) normally use beam splitter(s), neutral density (ND) or metalized Inconel filters, or a combination of these elements to reduce the laser beam intensity.

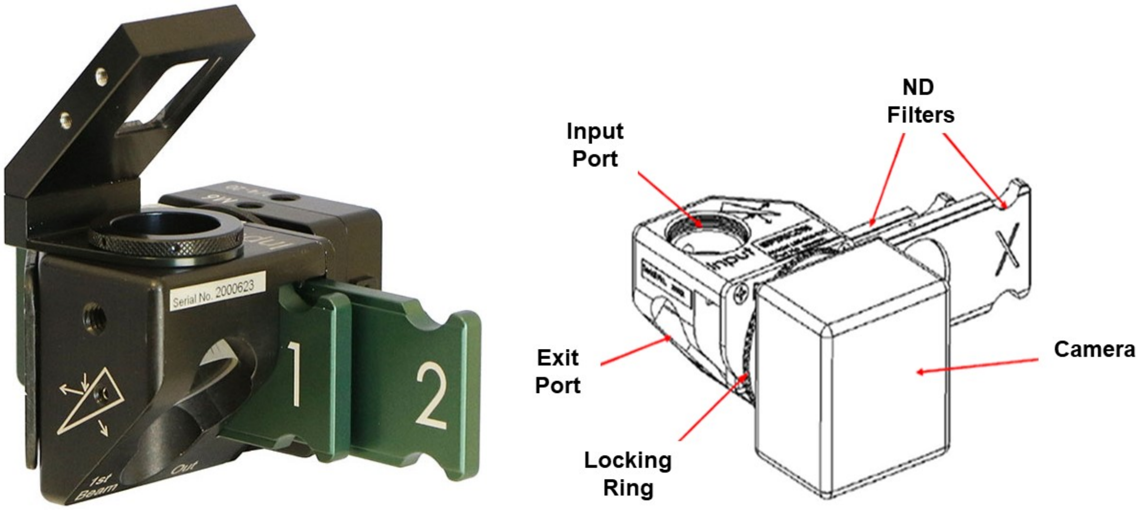


Figure 3. LBS-300 beam splitter/attenuator configured with a generic camera.

Most often, beam attenuation employs a combination of reflective and absorptive filters to reduce the intensity of a laser beam prior to its impingement on the detector array. The first stage of attenuation typically employs a reflective element when the power density of the beam has the potential to exceed the thermal lensing limit of the absorption filters. If polarization is important then reflectors should be used in pairs to maintain the polarity of the laser beam. Thermal lensing, or thermal blooming, is a phenomenon that occurs when the laser's energy heats an absorptive filter, changing the local refractive index near the beam and thereby forming a lens that can either focus or expand the beam. This phenomenon can be observed over a discernable timeframe at low laser powers ("blooming), or almost instantly at higher powers, giving the illusion of stability and accurate measurements. Thermal lensing must be avoided since it produces significant errors in the beam profile measurements. A basic rule-of-thumb for the safe, accurate use of absorptive filters is that the laser power is around 100mW per mm diameter or roughly 12.7W/cm^2. Since power density increases as beam size decreases, this means that a 100µm beam may show this effect at as low as 1mW of power. Actual usable power densities will vary, depending on the wavelength.

Ultraviolet and Infrared Beam Profiling

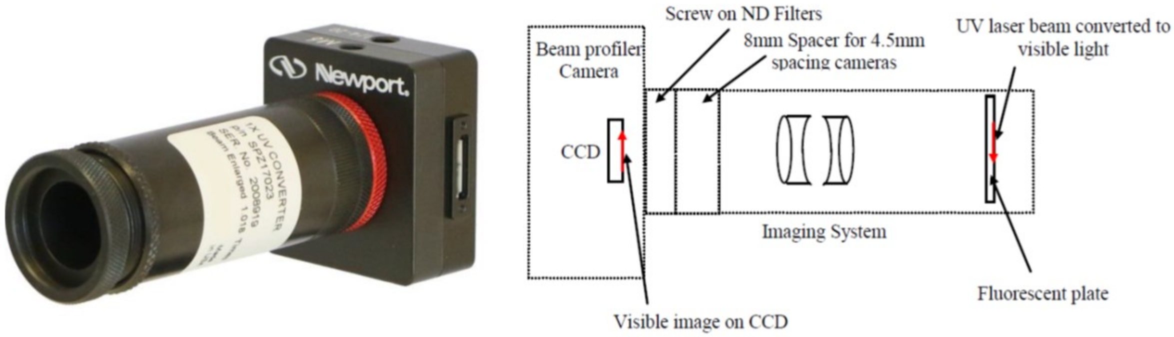
While CCD and CMOS detectors yield the best signal response for laser light in the visible region of the spectrum, it is frequently necessary to profile laser beams having wavelengths in the UV or IR regions. Specialized optics and coatings are required to profile beams under these circumstances.

UV Laser Beam Profiling

Newport supplies the LBP-UVIMG image converter for beam profiling of UV lasers. The converter employs a fluorescent plate that converts impinging UV light to a visible image. The fluorescent plate has a wide, linear dynamic range for the conversion of UV light to visible light along with a high optical throughput and a high damage threshold. The unit employs 1:1 imaging optics to transfer the visible image of the laser spot to the CCD detector in the beam profiling camera, as shown in Figure 4.

IR Laser Beam Profiling

Image conversion, like that employed in UV beam profiling, is used in adapting camera array beam profilers for use with near infrared (NIR – 1440 to 1605 nm) lasers. Newport's LBP2-IR and LBP2-HR-IR image converters use a phosphor coating technology analogous to the fluorescent coating plate in the LBP-UVIMG image converter. The Anti-Stokes phosphor coating produces visible photons at a rate roughly proportional to the square of the incident infrared light; the non-linearity of the signal can be corrected by a Gamma Correction function in the beam profiling software. It should be noted that the measured laser beam spot size is slightly larger than the true beam size due to the nature of phosphorescence.



(a) **(b)**

Figure 4. (a) LBP-UVIMG attached to a camera array profiler; (b) a schematic diagram of the components in a LBP-UVIMG Image Converter.

Electronic Processing and A/D Conversion Accuracy

Electronic processing and A/D conversion deal with variable such as gain, black level, linearity, signal-to-noise ratio, and the A/D conversion into a number of digital bits that represent the light intensity from each pixel. Most modern cameras have 12 or 14-bit converters that yield 4096 or 16,384 independent levels of intensity. Optimization of the camera control variables can typically produce signal-to-noise ratios of 58-63dB rms; a signal-to-noise ratio of 60dB in a typical 12-bit camera yields about 24 counts of peak-to-peak noise out of a total of 4096 counts. Cameras with higher signal to noise ratios that can digitize well into the noise have improved capability when making accurate quantitative measurements.

Conclusion

The foregoing note has outlined some of the considerations that are necessary when selecting a beam profiler for different laser light sources. The optimal choice of a beam profiler and certain ancillary components such as attenuators and image converters depends critically on the laser light wavelength, beam power, beam/spot diameter, and whether the beam is continuous or pulsed.

A more comprehensive tutorial on the current technology for beam profilers has been produced by Carlos B. Roundy and is available on the web (Roundy C. B., 2000) and as a book chapter in the more extensive treatise "Laser Beam Shaping: Theory and Techniques" (Roundy C. B., 2000).

References

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