Choosing the Right Detector for Laser Power and Energy Measurements*

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If you're reading the me·trol'o·gist, there's no need to explain to you the importance of good metrology in general. However, you may not realize the importance of good laser metrology and its many pitfalls until you realize how much of today's commonplace conveniences – from long distance communications to LASIK (laser-assisted in situ keratomileusis) to state-of-the-art cutting and marking tools – rely on modern optoelectronic devices. For example, there are numerous laser parameters to measure, such as power, energy, pulse width, angular distribution, spatial uniformity, and spectral content, just to name a few. Which of these is a critical measurement parameter depends on the application. While spectral content is a critical parameter for optical communications, power and spatial uniformity are important for LASIK. Choosing the right measurement tool can be just as confusing – there are optical detectors, beam profilers, spectrum analyzers, wavefront analyzers, and others too numerous to mention. The term "optical detector" alone can refer to the material from which the detector is made (germanium detector) or the principle upon which it operates (fast pulse detector). Despite apparent differences, the two labels may refer to the same physical device.[1]

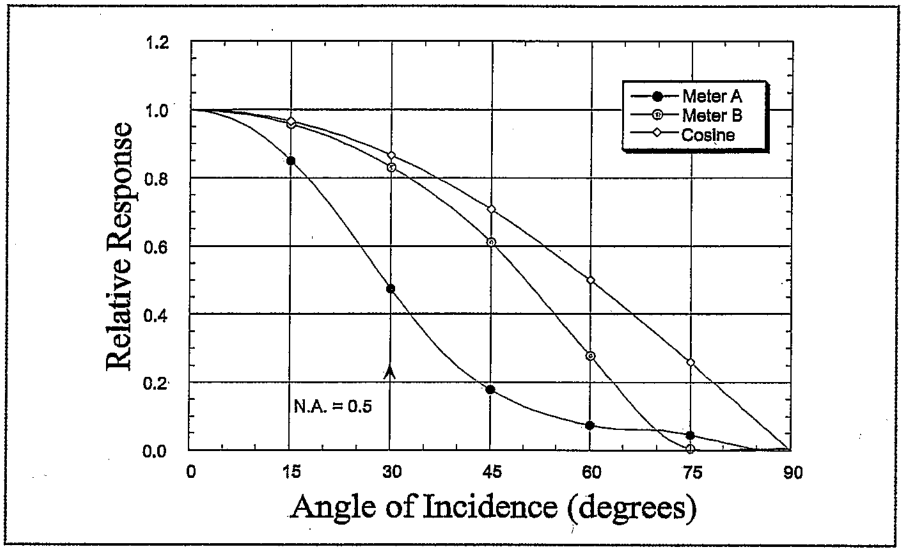

Figure 1. Angular dependence of two i-line (365 nm) dose probes.[2] The arrow indicates the relative response at a numerical aperture (N.A.) of 0.5. A significant measurement error can be introduced due to the imperfect cosine response of a dose probe. This offset would be unaccounted for if the meters were calibrated using a parallel beam but intended for use in a tool with off-axis illumination.

Let's consider laser metrology requirements for excimer laser photolithography, a microfabrication process for integrated circuits. It's important to understand the principal of operation behind an excimer laser photolithography tool for this discussion. An excimer laser source illuminates a mask. The mask contains the information that will be printed onto the wafer. The wafer is coated with an ultraviolet-sensitive photoresist. The projection optics transfer the mask pattern to the wafer. The resolution of the tool is proportional to the wavelength of the source divided by the numerical aperture of the projection optics. The numerical aperture describes the angular spread of light that reaches the wafer plane.

There are a number of laser measurements that are important for both tool development and performance. Measurements at the source are used as part of a feedback mechanism to stabilize the source's pulse energy. Like a photograph, there is an optimum laser exposure that will lead to the best resolution of small features at the wafer plane – over or under exposure of an object leads to reduced image contrast and poor resolution. Optical material characterization measurements, such as transmittance and birefringence, are important for tool development and performance as well. However for this article, we will limit the discussion to laser power and energy measurements.

There are several questions to ask yourself before purchasing a detector for laser power and/or energy measurements:

1. Is the detector for laser power or energy measurements? Do you want to measure individual or average pulse energy? You can measure average pulse energy with a power meter if you know the number of pulses and the repetition rate of your laser. In general, power meters are slower than energy meter meters. Some detectors, such as pyroelectric detectors, are only sensitive to pulsed sources. Also consider the power and energy range of interest in your selec-

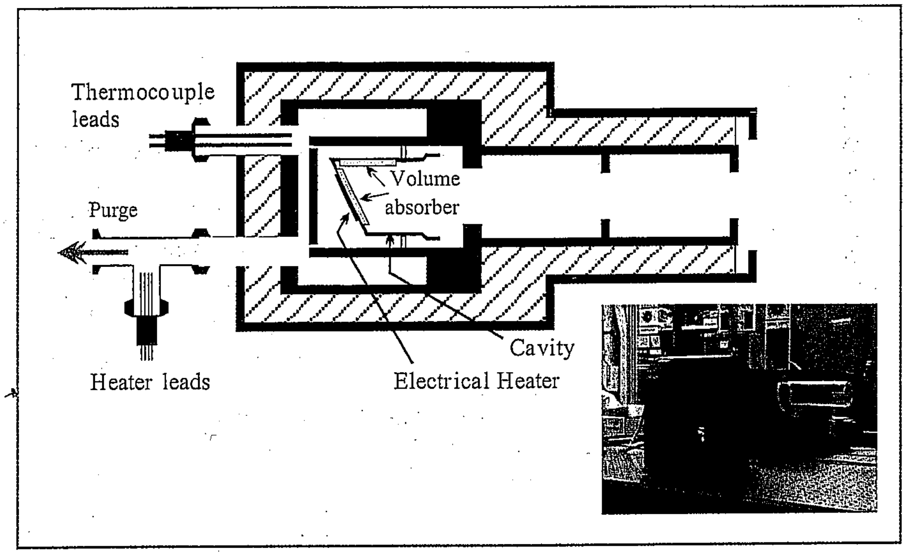

Figure 2. Schematic drawing of 193 nm primary standard calorimeter.

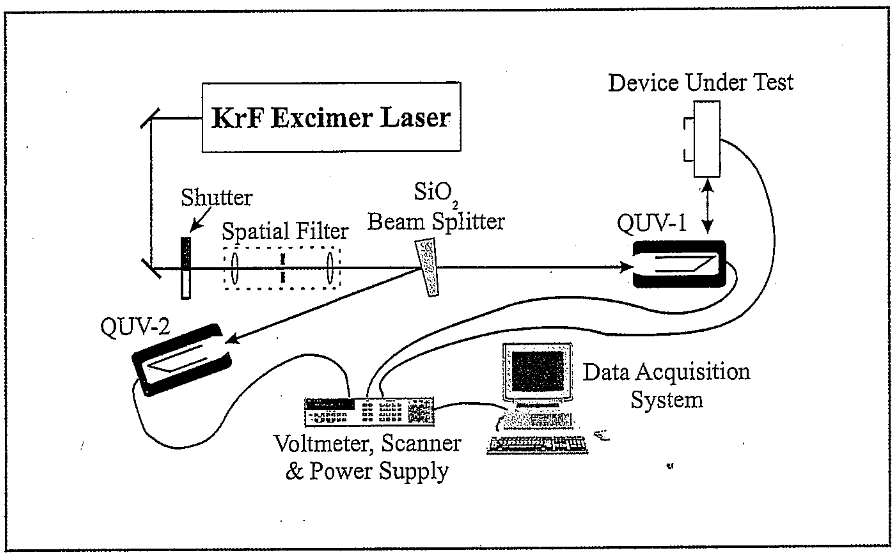

Figure 3. Schematic drawing of 248 nm excimer laser measurement system. QUV-1 and QUV-2 are the primary standard calorimeters. A 2° wedged, fused silica (SiO2) beamsplitter is used for monitoring the laser power and providing attenuation. This 248 nm system is similar to the 193 nm measurement system, although the 193 nm measurements are performed in nitrogen rather than air.

tion. Some detectors are linear over a wider range of laser power and/or energies than others.

2. Is the laser pulsed or continuous-wave (cw)? Keep in mind that although a pulsed-laser and a cw-laser may have the equivalent average power, you should take into account the peak power s when determining whether or not you will exceed a detector's damage threshold for pulsed-laser measurements.
3. Are spatial and angular uniformity important to your measurements? Spatial non-uniformities can lead to reproducibility problems if the size of your laser beam is small relative to the size of the detector. Angular uniformity can be critical in applications that use diverging laser beams. (See Figure 1.)
4. Will you be using this detector at several laser wavelengths? Is so, you should choose a detector with a spectrally-flat response or one where the calibration factor is specified at the wavelengths of interest.
5. What level of accuracy is important to your application? At NIST, we have developed primary standard calorimeters for laser power and energy measurements. (See Figure 2.) These electrically-calibrated calorimeters provide a direct comparison between optical and electrical energy, thus tying optical measurements to SI units. (Most commercial detectors are not electrically-calibrated; some detectors will detect only a fraction of the incident light because they have reflective surfaces. One can correct for the reflective losses by calibrating the detector against a primary standard or by measuring the surface reflectance. See Figure 3.) The overall expanded uncertainty associated with NIST calorimeters is typically less than 1%. However, measurements made with these calorimeters are time-consuming and difficult. You must consider the trade-off between accuracy and throughput in the detector selection process. Finally, for some applications, only the relative change in laser power or energy is important. Therefore, long-term stability rather than absolute accuracy should be your primary consideration in detector selection.

In conclusion, there are a number of issues to take into consideration when purchasing a detector for laser power and energy measurements. Choose carefully or risk performing the wrong measurement for your application. NIST offers an annual short course that covers many of the common measurement problems and concerns that arise in making accurate laser measurements. Finally, when in doubt feel free to contact me with your questions about accurate laser measurements.

References:

1. John Lehman, "Optical Detectors and Calibrations for Laser Power and Energy Measurements," NIST Laser Measurements Short Course (2007).
2. Cromer, C. L. and Bridges, J. M., "NIST Characterization of I-Line Exposure Meters," *SEMATECH Technology Transfer Document*, No. 91040516A-ENG (1991).

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