Position Sensitive Detectors for Test and Measurement

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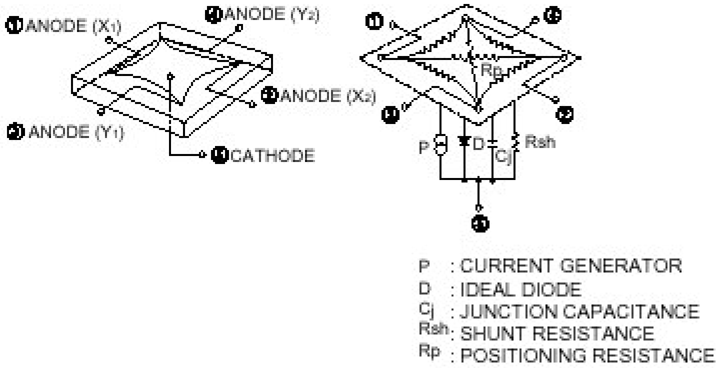
Introduction

Position sensitive detector (PSD) has been extensively used in physics researches for particle detection. There are many kinds of PSD systems for charged particles and photons/lights from infrared, visible, to X-ray. The position decoding anodes, however, are relatively limited. There are resistive anodes, anodes with wage-and-strip patterned, delay-line anodes, and multi-element detector arrays. The resistive and wage-and-strip anodes (Figure 1 and 2) decode the position information by comparing the currents collected at different electrodes. The delay-line method works for pulsed beam and get the position by comparing the signal timing delay between the electrodes.

Figure 1. Resistive Anode and Its Equivalent Circuit

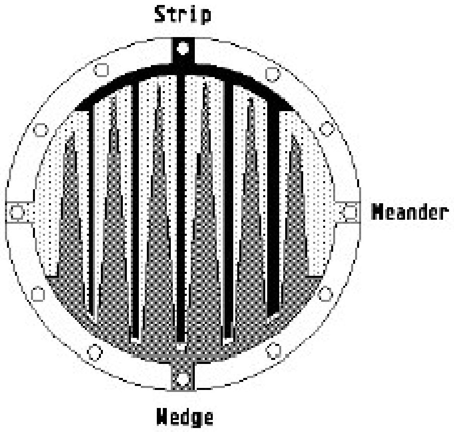


For a uniformly coated resistive anode, the current collected by an electrode is inversely proportional to the distance between the incident position and the position of the electrode:

$$X \propto \frac{(I_{X2}+I_{Y1})-(I_{X1}+I_{Y2})}{I_{X2}+I_{Y1}+I_{X1}+I_{Y2}}$$

$$Y \propto \frac{(I_{X2}+I_{Y2})-(I_{X1}+I_{Y1})}{I_{X2}+I_{Y1}+I_{X1}+I_{Y2}}$$

Figure 2. Wage-and-Strip Anode



The wedge-and-strip anode contains three different structures: wedges, strips with increasing width from left to right, and the space between the wedges and strips. The position information is obtained by charge division:

$$X \propto \frac{Is}{Iw+Is+\mathrm{Im}} \qquad Y \propto \frac{Iw}{Iw+Is+\mathrm{Im}}$$

To reach the better position resolution, the charge cloud must covers several structures to determine a mean value. The structures shown in the picture have been enlarged. The typical distance between the segments is about 1 mm.

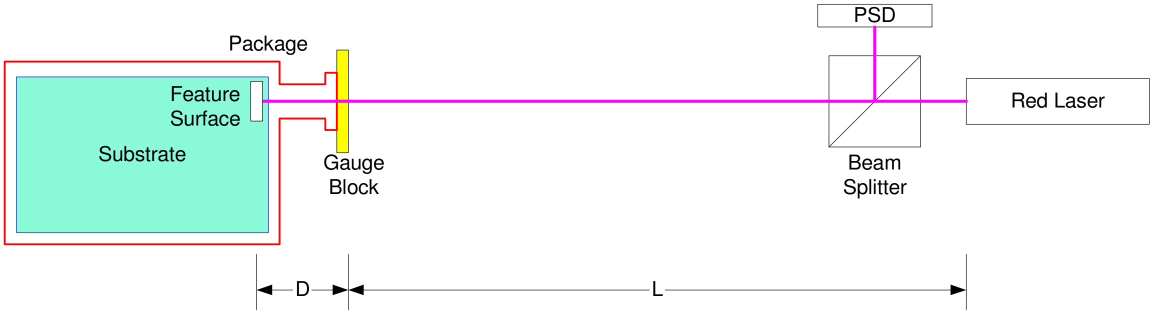
PSDs can be used for direct position and angle sensing in test and measurement applications. Based on the position information, other device characteristics such as motion and vibration can be measured. The followings are some of the PSD based applications being implemented in manufacturing processes.

Applications

Alignment Assistance

It is very common in manufacturing processes that require parts to be aligned parallel, perpendicular, or in other angular relationship with each other. With high position resolution and fast response time, PSDs are good choice for active feed back in process automation. Two applications are illustrated here for optical component manufacturing. The basic principle can be easily applied to other manufacturing processes.

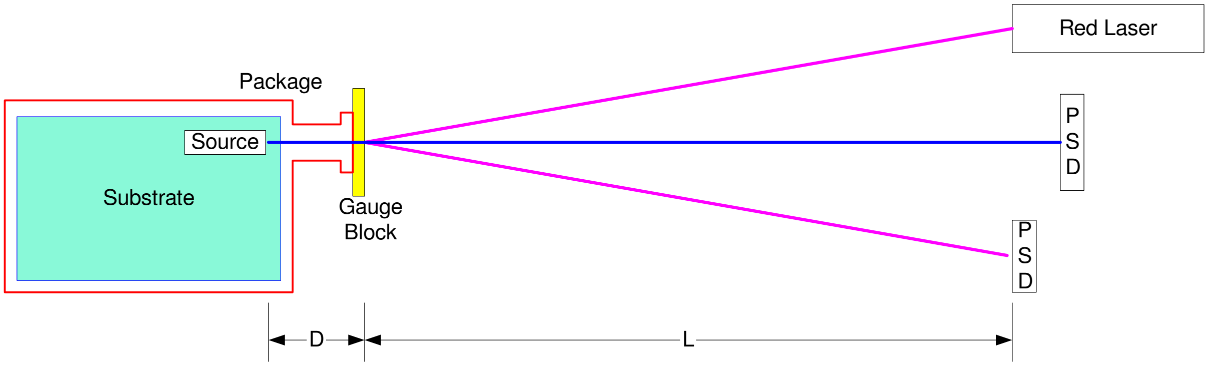
Figure 3. Using PSD to Align the Substrate Parallel to the Package



During the optical component packaging processing, substrates need to the aligned with high accuracy to packages to achieve high pigtail yield. Figure 3 shows an alignment scheme that uses a visible red laser and a PSD to align the substrate relative to the package. The manufacturing product is a passive device and the alignment requirement is to ensure that the surface of a feature on the substrate is parallel to the package snout front surface. In this packaging process, the snout front surface is first registered on the PSD using the reflective and parallel gauge block magnetically attached to the snout. Next, the gauge block is removed and the substrate is aligned until the reflected beam from the feature surface hits the same position on the PSD.

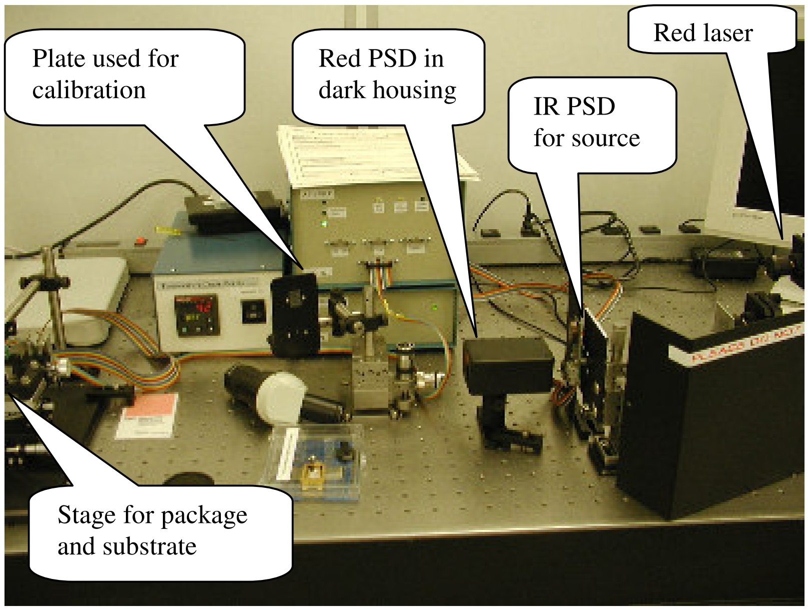
The alignment error in this setup comes from the non-perfect perpendicularity between the laser beam and the snout front surface and the non-negligible distance between the snout front surface and substrate feature. It can be quickly show that the angle error $\alpha \approx \delta D / 2L^2$, where δ is the distance between laser exit beam and reflected beam at the laser. The PSD resolution is typically better than 10 µm, thus negligible in this error analysis. When the red laser is initialed aligned to be perpendicular to the snout using the retro-reflection method, δ is limited by the beam size, typically about 1 mm. For D ~ 10 mm and L ~ 200 mm, the system error α is about 0.007°. Such high resolution is unmatchable for expensive vision systems. In addition to the high position resolution, PSDs offers high-speed response (in microseconds), low cost, and good reliability.

Figure 4. Using Two PSDs to Align the Source Output Perpendicular to the Package



For active devices where the source output beam need to be aligned, Figure 4 shows one possible alignment method. This alignment methodology is very similar to that in Figure 3. Again, the package position is first fixed in space by requiring the reflected beam from the snout front surface hitting the target position on the bottom PSD. The substrate is then aligned so that the source output is on the target of the top PSD. But unlike the setup in Figure 3 which is self calibrated. The targets on the two PSD have to be calibrated during the station setup and the calibration needs to be constantly monitored to ensure optimized process. (The calibration procedure is beyond the scope of this paper. Please contact W2Lab for the detail.) The alignment laser and the bottom PSD can be in the visible spectrum. The selection of the top PSD, visible, near-IR, or something else, depends on the type of source being processed.

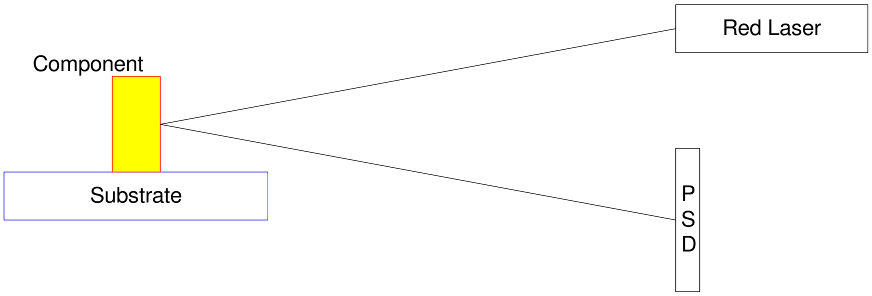
Figure 5. A Production Packaging Station Based on Figure 4



Out-of-Plane Angle Measurement

In manufacturing processes where components are placed with the passive pick-and-place tools, component location measurement is a very important metrology step. For in-plane positions, measurements are mostly based on vision systems, such as commercial systems from J-AMR. Using the auto-focus, these systems may also be able to measure the depth (Z-Axis) at reduced resolution. What is missing in these measurements is component out-of-plane angle, which is critical for optical devices.

Figure 6. Measurement for Component Out-of-Plane Angle Measurement

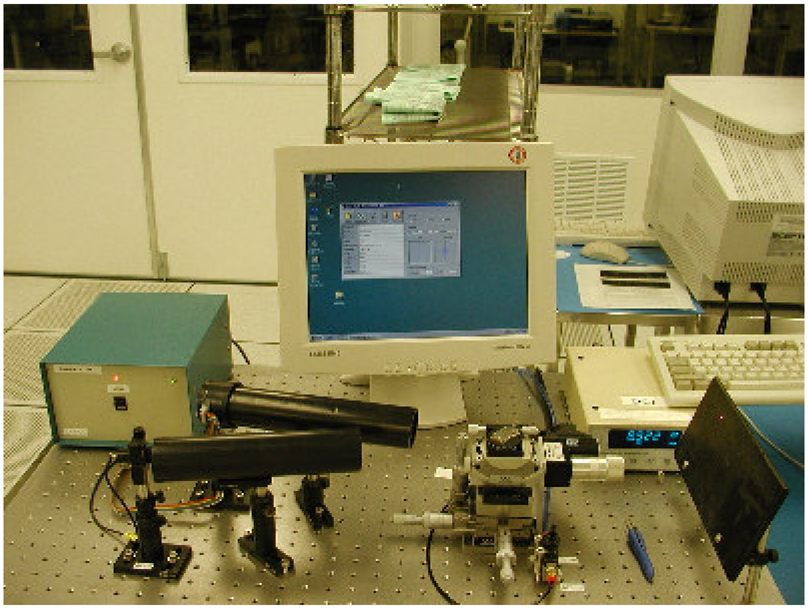


A novel optical method for out-of-plane angle measurement based on PSD is shown in Figure 6. The basic idea is to measure the angular position of the component by detecting the beam reflected from its surface. The (out-of-plane) angle between the part and the substrate is translated as the position of the reflected light on the PSD. The "zero" position of the PSD is calibrated using a perfect 90° prism in replacement of the substrate. For simple applications, the out-of-plane angle can be directly calculated from beam position relative to the "zero" on the PSD.

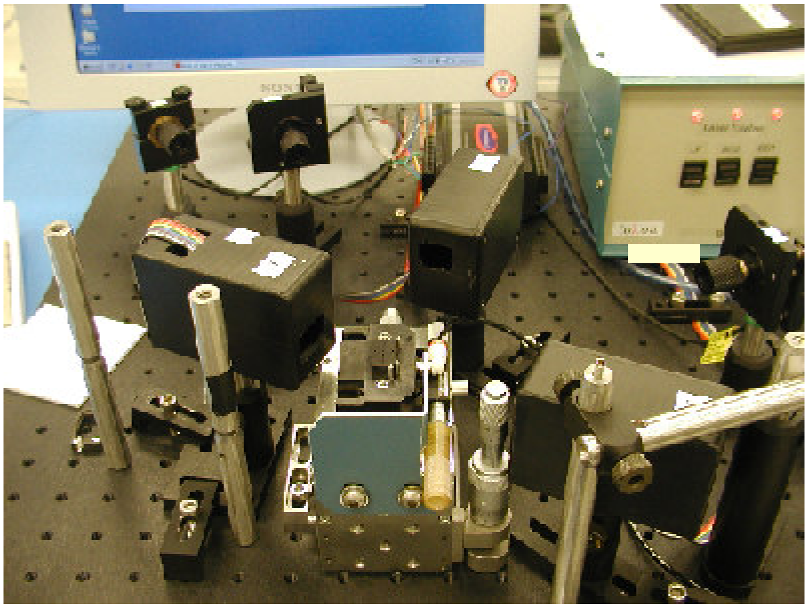
The angle calculation requires PSD calibration and consistent distance between the part and the PSD. For some test systems, such requirement may be too cumbersome or may result a measurement error too big to tolerate. This can be improved by using a goniometer as the stage for substrates. The measurement process now becomes rotating the goniometer until the reflected beam hits the PSD calibration point (the "zero"). The amount of rotation read from the goniometer is the out-of-plane angle. Modern goniometers with optical encoder can easily reaches 0.001° resolution. The top picture in Figure 7 shows such a measurement system.

For substrates with multiple components, a multiple laser-PSDs can be used to simultaneously measure the out-of-plane angles for all the components and the in-plane angles among the components (Figure 7, bottom picture). PSD based in-plane angle measurement like this has significantly higher throughput than the vision system.

Figure 7. Production Setups for Out-of-Plane Angle Measurement



Setup based on PSD and goniometer with optical encoder for high accurate out-of-plane angle measurement

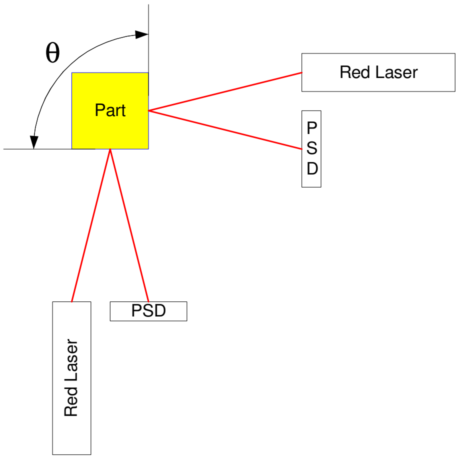


A 3-laser/PSD setup for multi-component measurements, out-of-plane and in-plane angles

Component Angle Measurement

The out-of-plane angle measurement illustrated in Figure 6 has one drawback. It requires clean surfaces between the substrate and the nest it sits on. Particulates under the substrate may cause substrate tip-tile, thus the measurement angle error. For many applications where the substrate cannot be the turned sideways, it remains be a good methodology. But for components that can sit sideways, a two-PSD system such as that shown in Figure 8 is more efficient and accurate. A test bench based on this is being used to screen components for tilt before thery are planced onto substrates.

Figure 8. A Two-PSD System for Component Angle Measurement



Angle ϑ can be calculated by comparing the beam position on the PSDs with response to the calibration points. Similar to that shown in Figure 7, using rotational stage with digital encoder may improvement system compactness and system accuracy at the expense of high cost.

The methodology shown in Figure 8 is very universal. It can be used for any components with some reflection, either visible or IR. The system can be calibrated to measure any angle (ϑ can be none 90^o value) with high resolution, which can be improved by increasing the distance between the part and the PSDs.

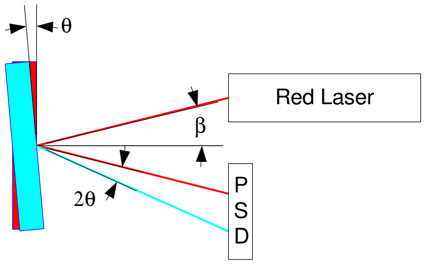
Surface Flatness Inspection

A deviation of Figure 8 can be used for surface flatness inspection. If the parts mounted in a linear stage, by moving the part the laser beam will scan across its surface. PSD position change as a function of parts position reflects the part surface flatness. Because of the fast response time of the PSDs, the scan speed is limited only by the speed of the motion system.

Displacement Measurement and Motion-Vibration Characterization

PSDs can be further used to measure the dynamic characteristics of the devices, such as motion linearity, frequency response, and vibration. Figure 9 illustrates the basic principle for the rotary motion detection.

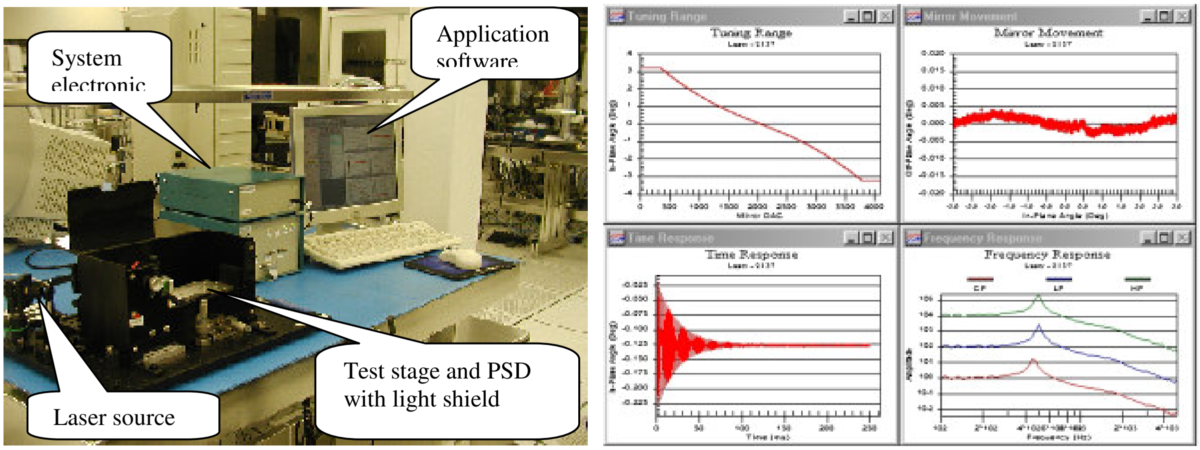
Figure 9. PSD for Motion Characterization



A laser beam is bounced off a reflective surface on a rotary actuator. For each actuator rotation of ϑ, the reflected beam moves 2ϑ resulting a beam shift on the PSD.

Figure 10 shows a production bench used to characterize MEMS (micro electric mechanical systems) actuators. By measuring the beam position on the PSD as functions of actuator driver signal and time, it measures motion linearity (top left plot), smoothness (top right), time (bottom left), and frequency (bottom right) response. Frequency response is deduced from the time response using Fast-Fourier Transformation (FFT) technique. The station has a 0.002° angular resolution over a ±4° dynamic range. The time resolution is limited by the speed of data acquisition (DAQ) card. Using a 330 kHz DAQ card, this setup achieves 0.01 ms time resolution and measures frequency response up to 10 kHz.

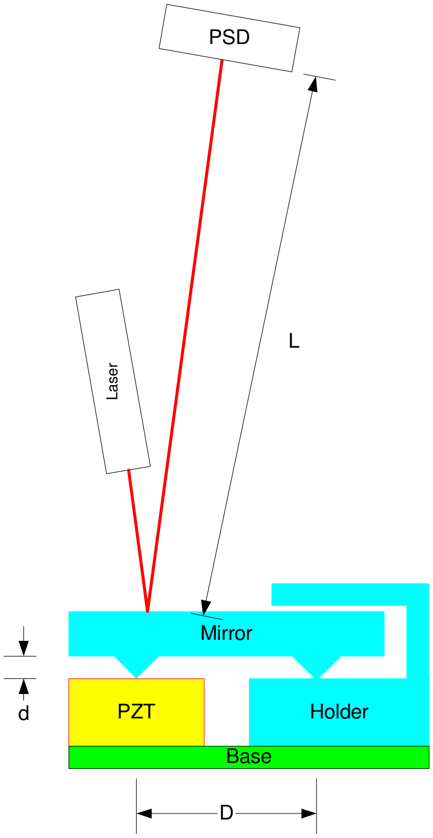
Figure 10. Production Station for Micro Actuator Characterization



Applications for linear motion is a bit more complicated than those for the angular motion. For a setup like that shown in Figure 9, the part movement in the up-down direction will not change the beam position. A left-right motion, however, will cause some beam shift if the laser beam is not normal to the part: $X = 2d\tan(\beta)$, where X is the displacement on the PSD, d is the part displacement, and β is the incident angle. For small incident angle, $X \approx 2D\beta$, resulting a linear relationship between the PSD position and the motion. Although the small angle also reduces the displacement on the PSD, the method has enough resolution measuring devices with large displacements. For a typical PSD resolution of 5 µm, the measurement resolution is 0.07 mm at $\beta = 2^\circ$, and 0.03 mm at $\beta = 5^\circ$. Such resolution can be sufficient for devices that move a few centimeters (with a few tenth of a percent relative resolution).

For small motions, an amplification scheme is needed. Figure 11 shows the principle of an application used to measure the displacement of piezo devices. It can be shown that for $d << D << L$, the displacement on the PSD $X = 2dL/D$. At D = 5mm and L = 500 mm, the measurement resolution is 0.025 µm for the PSD with a resolution of 5 µm. The movement range of the piezo devices is 3 µm. This results a system resolution better than 1% for micrometer motion, on par with the expensive interferometers.

Figure 10. Schematic for a Piezo Displacement Inspection Station



Beam Separation and Angle

The position signal generated by the PSD is based on the "center of gravity" of charge clouds. So a PSD operated in the DC mode will not be bale to distinguish two incident beams. Instead, it gives out a false position that is the average of the two incident beam positions weighted by their inensity. This shortcoming can be overcome using optical switches. This allows PSD to measure the beam separation and further the angle between two beams.

Figure 12. Schematic for Beam Parallelism Measurement

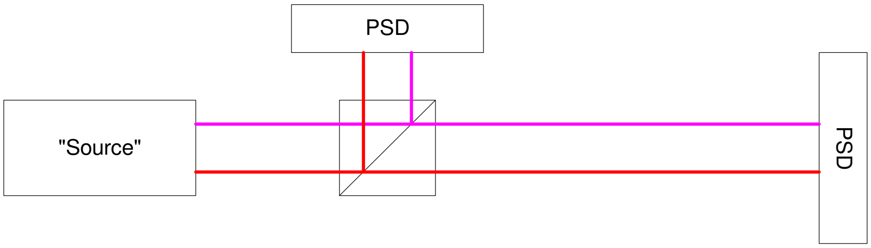


Figure 12 outlines a measurement scheme used to measure the separation and parallelism of a dual output fiber collimator. Output beams are split by a beam splitter and detected by two PSDs, one at near field and the other at far field. The beam positions on the PSDs are measured separately by switching between the two beams, say "red" first and "magenta" next. The beam separation is then calculated by comparing the "red" and "magenta" positions on the PSDs. From the beam separations at the two PSDs, beam parallelism (or angle) is then calculated from the known distance between the two PSDs. For two PSDs at 60 mm apart with a 20 µm mismatch, the angular resolution is 0.02^o. Besides the collimators, this methodology is also used to measure prisms, beam splitters, and other optical components.

Light Sources, Detectors, and Signal Processing Circuits

A typical application will need the following hardware:

- Light sources, typically the diode lasers
- Position sensitive detectors
- Signal processing circuits
- Signal readout: digital multi-meters, panel meters, or computer data acquisition card
- Optional software programs for data deduction and analysis

Most of the applications can be implemented using the diode lasers and PSDs in the visible spectrum where light sources and PSDs are readily available and are relatively cheap (Depends on the applications, a red diode laser costs from $19 to $300). This also allows direct visualization of the beam thus eases the initial setup. The difference is in module package, power, and beam quality. The silicon PSDs for the visible and near IR light are cheaper than other types. A large 9 by 9 mm PSD costs only $50 while a 10 mm IR PSD costs up to $700 (Table 2).

Table 1. Selection of Laser Diode

Module	Power (mW)	Wavelength (nm)	Beam Characteristics
W2Dio-F-635	4.0	635, red	Circular beam, $\phi = 4$ mm, 0.40 mrad divergence
W2Dio-F-650	2.5	650, red	Circular beam, $\phi = 4$ mm, 0.50 mrad divergence
W2Dio-F-670	0.95	670, red	Circular beam, $\phi = 4$ mm, 0.40 mrad divergence
W2Dio-V-650	3.5	650, red	Circular beam with variable focus, $\phi \sim 0.5$ mm
W2Dio-V-670	0.95	670, red	Circular beam with variable focus, $\phi \sim 0.5$ mm
W2Dio-V-780	3.5	780, IR	Circular beam with variable focus, $\phi \sim 0.5$ mm
W2Dio-V-790	3.5	790, IR	Circular beam with variable focus, $\phi \sim 0.5$ mm
W2Dio-V-850	3.5	850, IR	Circular beam with variable focus, $\phi \sim 0.5$ mm

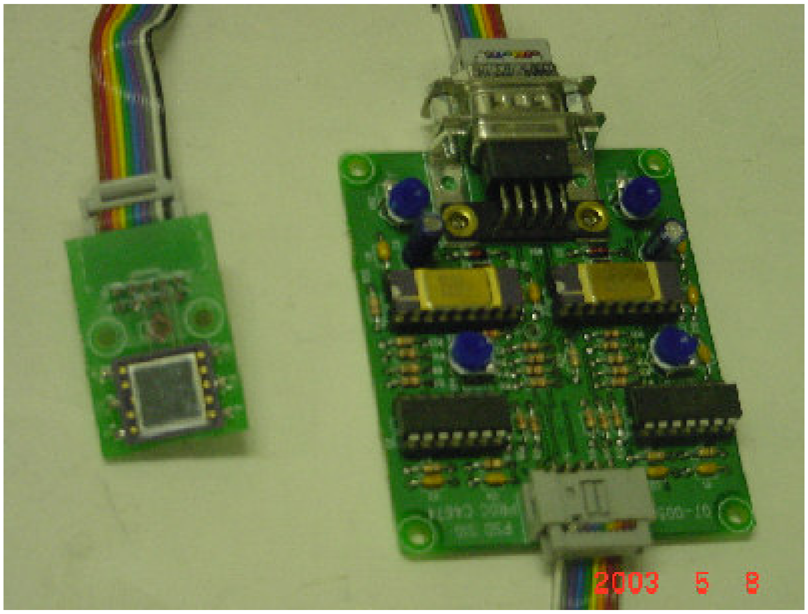
Table 2. Some Two-Dimensional PSDs in the Market

Model		Material	Package	Response Range (nm)	Active Area (mm)
Resistive Anode	W2PSD-Si-4	Silicon	Chip Carrier	320 to 1100	4 × 4
	W2PSD-Si-9	Silicon	Chip Carrier	320 to 1100	9 × 9
	W2PSD-Ge-5	Germanium	TO-8	800 to 1700	$\phi = 5$
	W2PSD-Ge-10	Germanium	TO, 1 inch	800 to 1700	10 × 10
	W2PSD-Ge-13	Germanium	TO, 1 inch	800 to 1700	13 × 13
Quad	W2Quad-Si-2P	Silicon	Plastic	320 to 1060	2 × 2
	W2Quad-Si-2T	Silicon	TO-5	190 to 1000	2 × 2
	W2Quad-InGaAs-2T	InGaAs	TO-5	900 to 1700	$\phi = 2$

For most of the applications, the cheap silicon detectors for the visible light are enough. The expensive germanium PSDs is useful mostly for the near-IR beam detections (*e.g.* the alignment and measurement of fiber-optical components) and applications where room light causes interference. The quad detector arrays are listed here because they can use the same signal processing board.

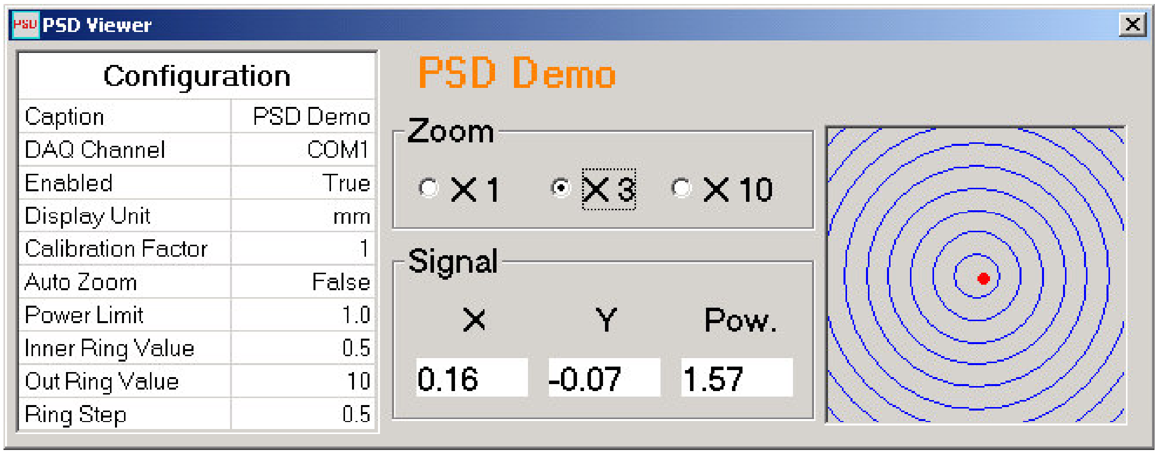
The PSD outputs current signals that are typical less than 1 mA. Current amplifiers and other circuits are needed to amplify the signals and to calculate the positional information for direct readout. In addition, some PSDs require bias voltage for optimized operation. W2Lab offers a generic signal-processing board that works for all the PSDs listed in Table 2. Also available are daughter boards for easy PSD mounting and quick PSD to board connection. The module outputs voltage signals (-10 to 10 V, adjustable) proportional to the beam position and intensity.

Figure 14. Signal Processing Board and PSD Mounting Board



An all-in-one instrument module in the standard 2U half-rack size is also available. The module includes diode laser power supply, PSD signal process board, optional panel meters, and optional computer data acquisition board. Free software program and development kit is provided with the data acquisition board. The software (Figure 14) allows direct visualization of the beam position in the calibrated space (distance or angle).

Figure 14. PSDView Allows Direct Visualization of the Beam



Configuration	
Caption	PSD Demo
DAQ Channel	COM1
Enabled	True
Display Unit	mm
Calibration Factor	1
Auto Zoom	False
Power Limit	1.0
Inner Ring Value	0.5
Out Ring Value	10
Ring Step	0.5

PSD Demo

Zoom

○ X 1 ● X 3 ○ X 10

Signal

X	Y	Pow.
0.16	-0.07	1.57