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A Review and Analogy of Laser Ray Tracing

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Abstract: The main equipment in laser ray tracing systems is Optical position sensors. Since these sensors are used in different applications, the weaknesses and strengths of choice for the intended use is of utmost importance. In this paper, the structure of optical detectors are checked. Then, the detector along the respective parameters, are analyzed. The strengths and weaknesses of each study are determined and the results are compared in the table.

Keywords: sensitive position detector, foursome detector, photodiodes, photodiode side effects, laser ray tracing.

1- Introduction

The first step is to guide the laser, is detecting the laser beam. Knowing the direction and the laser beam, the given equipment can be controlled to the direction and orientation. To identify and locate the laser beam, specific optical sensors are required. Optical sensors are equipment that and convert incident light to electrical signals. By processing and analysis of data, the location of the laser beam can determine [1]. In research, especially in the military field, extensive studies have been conducted on guided laser equipment. Use of laser-guided equipment began in America Air Force during the Vietnam War since the 1970s. The first advantage of this type of weapons was confirmed in this war proved in precision destroying targets with relatively small dimensions but with high importance. Today, laser weapons are used much wider for operations against enemy targets armor and protection. The biggest advantage of this type of weaponry is their high precision that can destroy the precise goals with the least amount of ammunition. Another advantage of using these weapons is the possibility of targeting a point precisely for consecutive times that is very efficient to eliminate armor targets.In recent years, military studies and the correct choice of materials for the manufacture of tracker systems pay special attention to laser detectors [2]. In this paper, the optical sensor is checked. Then a variety of applied sensors can be studied [3, 4, 5] and finally comparing different types of detectors are done based on their abilities and the tracking laser beam as the proper exposure for purpose of this article is determined.

2- Photodiode

To determine the intensity of incident light, it is necessary that the incoming photons to measurable signals are converted. For this purpose, photodetectors are used. Optical instruments are in several different classes. In photodiode, through the transfer of energy from photons to semiconductor materials electrons, electrical current is created. In this case, photons energy is absorbed by the semiconductor and electron-hole pair is produced. For the occurrence of this event, incident photon energy should be greater than the semiconductor material gap energy. A photodiode circuit p-n, is made by entering n-type impurity into the p-type semiconductor volume or vice versa. Through strong internal electric field, an empty area in takes place. When light enters the photodiode with enough energy, and electron-hole pair is created. When it happens in an empty area, by an electric field in an empty area, electrical carriers (holes and electrons pair) are separated. If paired electrons or holes are formed outside the area empty, if they have the ability to spread from the edges of the empty before combining, they can participate in the production process. Flow occurred, called optical flow, strongly depends on the incident light. In Figure 1, the photodiode, incident light, electron-hole pair formation in the layer p, empty area and n type volume are shown.

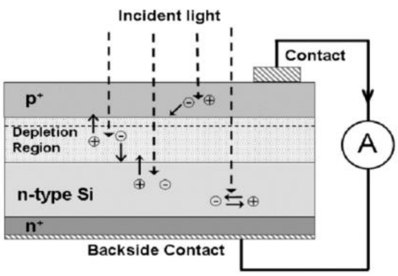


Figure 1: photo-diode structure [1]

2-1- Optical flow:

Optical flow is stream which is obtained by the produced carrier due to the intensity of incident light. Carriers are produced in an empty area, in a specify length called spread length and by electric field caused by bias voltage $\mathbf{V_{bi}}$ which is usually reverse It moves to the to both sides of the connection and then separated. The electrons move to n and the holes to the p region. The resulted flow of these carriers which is arisen by light, determine optical flow as follows.

$$\mathbf{I_{op} = qAg_{op}(L_p + L_n + W)} \qquad (\mathbf{1})$$

Where q is electric charge, g_{op} is the slope of the production per volume and time unit, A is cross sectional equipped area. L_p and Ln are the length of semiconductor region of n and p in the broadcast length of empty area that are derived by the following equation.

(2)

Where $D_{n.p}$, is the diffusion coefficient of electrons or holes, $\tau_{n,p}$ is the half-life of recombination of electrons or holes and W is the width of depleted area which is given by the following equation.

$$w = \sqrt{\frac{2\varepsilon_s V_{bi}}{qN_B}} \qquad (3)$$

Where ε_s is dielectric constant,V_{bi} is a reverse bias voltage and N_B is injected impurities.
When we compare it with equation diode current, the flow detector can be achieved. Diode current equation is as follows:

$$I_d = I_l\left(e^{qV/KT} - 1\right) \qquad (4)$$

By comparing produced flow of light, we can write:

$$I_p = I_l\left(e^{qV/KT} - 1\right) - I_{op} \qquad (5)$$

Where V is the bias voltage. To view the total flow of reverse current, diode detector is added. Diode reverse current, I_l leakage current is considered. Silicon photodiode can be written:

$$I_l = A.q\sqrt{\frac{D_p}{\tau_p}}\frac{n_i^2}{N_D} + \frac{qn_iW}{\tau_e} \qquad (6)$$

Where τ_p and τ_e are the duration of recombination of holes and electrons. $D_p$is diffusivity holes, N_D is the injected concentration,n_i is the concentration of intrinsic carrier, W is the wide of empty area, q is primary load and A is the area.
Intrinsic carrier concentration$n_i$is given by the following equation:

$$n_i = \sqrt{N_c N_v}e^{-(E_g/2KT)} \qquad (7)$$

Where N_c and N_v are the effective density of states in the conduction band and valence band. K is Boltzmann's constant with a value of1.38×10^{-23}, T is the heat degrees in Kelvin and E_g is Power Section gap.
Photodiode work under reverse voltage. In these circumstances, the width of empty area is increased and also, depletion capacity is reduced. In addition, the higher the electric field, carrier speed drift increased, so carrier transport time will be less. Figure 2 shown the current-voltage diagram of a silicon photodiode without lighting (solid line) and with the brightness (line with circles) [1].

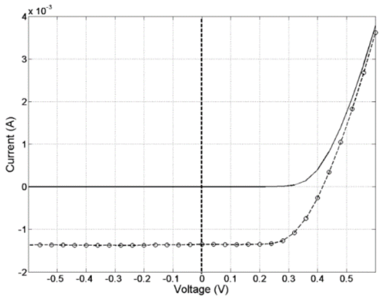


Diagram 2: Flow - voltage silicon photodiode [1]

2- Equivalency circuit:

A photodiode can be described by using discrete components in a circuit as shown in Figure 3.
In the figure above, current source I_{op} is the current generated by the incident light, i_d is the ideal diode current$p - n$,C_d is capacitance coupling, $R_{sh}$is shunt resistor of parasitic elements that represent the dark resistance, contact resistance at zero bias and R_s is series resistance. [1]

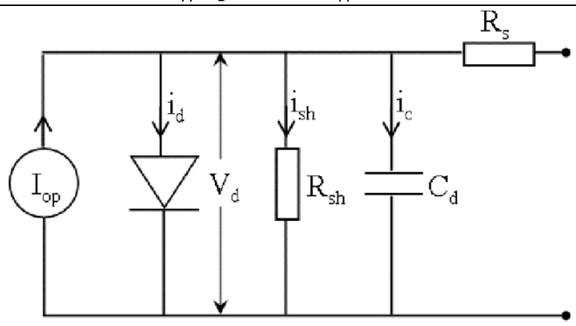


Figure 3: The equivalent circuit of the photo-diode[1]

3- Position-Sensitive Detector PSD

Position-Sensitive Detector (PSD) are simple photodiodes with a resistive layer that is enable to detect light spot central location (usually laser light) on the surface to reveal [3 and 1]. PSD is a critical component of semiconductor electric light that have been developed to measure the instantaneous position, displacement, vibration, etc. there are Various methods for revealing the location of the incident light. These methods include using a small detector arrays or CCD sensors and the use of separate and distinct detectors that make a continuous information of the position by the resistance level of the photodiode [3 and 6]. Output analog signals from the PSD, represents the position of the incident beam spots on its sensitive surface. Compared with the CCD equipment, PSD has characters such as high sensitivity, high responsiveness, simple detection circuit and also consistently sensitive level. Because the analog signals are used, they are easily affected by ambient stray light, to solve this problem the optical filter is used. Output analog signals PSD, can only detect the center of gravity of the incident light energy. Because of this, it cannot do more image processing than digital signal for CCD [6]. Optical flow which is produced by the position of the light spots on the surface, are divided on the surface of the detector by fitting. Resistance of the surface is in a convenient distance of connections and flows will split according to the resistance path. Then the location of the spot position of signal amplitude ratio produced is calculated. Resolution is limited by stability, shape and size of the halo of light spots and the measuring equipment. It is to be noted that the current ratio with a compact center is equivalent to the brightness of the surface of the detector. A change in the shape of the stain, for example, may have a compression on measurement results by fluctuations in the laser modes. For resolution in the micron range, there is a need for high quality measurement equipment. In order to detect a 1 micrometer in the position of spots in the PSD as much as 10 mm, it is required that the flow measure by a precision better than 0.01%. This is definitely can be achieved for example by lock-in amplifiers in combination with light sources that are produced with pulsed. The limitations in achieving a resolution, will be determined by changes in the dark current caused by thermal emittance or local heat energy of fluorescent spots. Surfaces that are exposed to high temperatures due to the brilliance should generally be avoided [7]. Position-Sensitive Detector use photodiodes side effects that were known by their discovery in 1957 by Wallmark. Although this work was described in 1930 by Schottky, but Side effects were described by Lucovsky in details and then they are further developed by many researchers. Light incident on the detector turns into the electric current. The flow is split between the connectors, proportional to resistance of active layer of the incident light spot position to connections. By comparing the current amplitude ratio obtained from each connection, the position of the spots can be determined. A PSD side effect creates very high resolution and fast response is appropriate especially when very small movements in real time is required. In general, PSD can be used in non-contact displacement measurement.

4- PSD division:

In general, PSDs are divided into two main photodiodes side effect (continuous) LEP and four detector or separate gates QD. PSD are made in $\mathrm{Duo-LateralandTetra-Lateral}$. We are going to examine each of them as follows [1, 2 and 4].

4-1 one dimension photodiode side effect:

According to Figure 4 photodiode side effects is a Position-Sensitive Detector which include a simple photodiode with a widespread area that a uniform important coating is on it. The photodiode has two connectors on the sides of streams to extract the light which is different and a common cathode connection. Side photodiode is flat and continuous elements photodiode (without gaps or dead zone) which read out the position of the light spots around the active area directly by providing analog output. The output analog is formed intensity and by the position of the light spot on the active area detector. A side effect photodiode is usually made of a Schottky connection or p-n junction. Carriers are generated by incident light spread through the resistance mass. Then they are separated by the field of the bias voltage and are divided between the two connections proportional to the strength of the connections. Side effect Photodiode, determines the position of the center of gravity of the incident light as long as the spot size is not larger than the detector and is not sensitive to the shape and size of stain. If the spot size is larger than the active region between the center of gravity of the main landing light and the center of gravity of light formed on the active surface, there is diversity of positions and provides unreliable measure. So the choice of PSD proportional to the cross-section of the optical spot size is essential. To obtain a good position of PSD, and in order to stay in their linear region and not saturated, wandering lights and leakage current can be compensated. The main benefit of photodiode is a wide range of side effects and its continuous output signal wavelength. Due to the lack of grooves on the photodiode side effects, electrical signal is generated across the active area. A high position resolution and fast response times are the most important characteristics. The great disadvantages of the side effect photodiode detectors is relatively high noise [5]. In contrast they are in a large dynamic range so that they measure the right spots to the position outside edges. These center sensors measure the intensity of the spot light distribution so they are indifferent in the form of spots. Generally they are pretty good for measuring the optical spots [4].

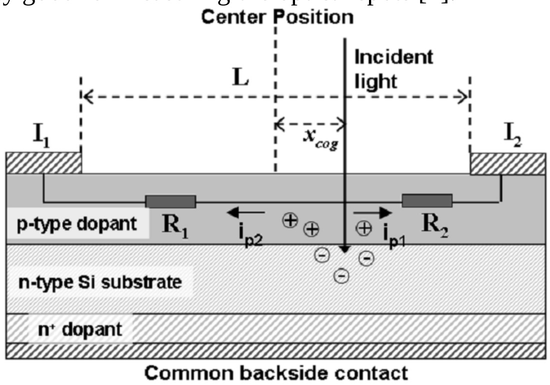


Figure 4: LEP Structure [1]

The final flow for side effect photodiode is the same equation 2-5 that was previously achieved for photodiode. If the p-type layer resistance is considered perfectly uniform layer, then two resistanceR_1 and R_2 are only proportional to the distance to connections. This means that the currents I_1 andI_2, acquires exact position of i1 and i2 flows rate, the exact position of x_{cog} is achieved. I_{p1}andI_{p2} flows rate, the leakage current I_L and other currents, contribute in I_1 and I_2. The center of gravity positionx_{cog}, can be determined by the final cross-flow distribution along the length.

$$x_{cog} = \frac{\int_{-L/2}^{L/2} x.I_{psd}(x)dx}{\int_{-L/2}^{L/2} I_{psd}(x)dx} (8)$$

Where I_{psd} cross-flow distribution and x is location. So you can write:

$$\frac{I_1}{I_2} = \frac{R_2}{R_1} = \frac{0.5L - x_{cog}}{0.5L + x_{cog}} (9)$$

Where L is the length between connections in PSD and x_{cog} is the center of ultimate current gravity. By rewriting the current relations for the center of gravity or light spots we have:

$$x_{cog} = \frac{L}{2} \cdot \frac{(I_2 - I_1)}{(I_2 + I_1)} \quad (10)$$

The above equation is the PSD in which the relationship position of the light spot with a value between positive and negative is half-length of L [1].

4-2- two-dimensional side-effect photodiodes:

Two-dimensional side-effect Photodiodes are used to determine the location of the incident light spots in two dimensions on the surface of the detector. In aligning applications, they can be used where a laser or other light source are on the fixed position and two-dimensional detector is located on an object or laser light reflected from the object goes. Two-dimensional detectors are divided into two categories dipole and quadrupole [2-4V 6 and 8].

4-2-1- bipolar photodiodes Side effects

To measure the position of the light in two dimensions, generated optical flow will be split between four connections. Side effects of bipolar photodiodes includes two connections at the top and two connections at the bottom. In the side-effect bipolar photodiode, both the diode is used, so that it gives good linearity capabilities and reached the lowest error rate and increased resolution result [4]. But it makes more complex processes in its connections to the detector. Figure 2-5 presents the signals of location of x light spot emitted from the x electrodes on the upper level while the signals of location of x light spot emitted from the y electrodes on the upper level.

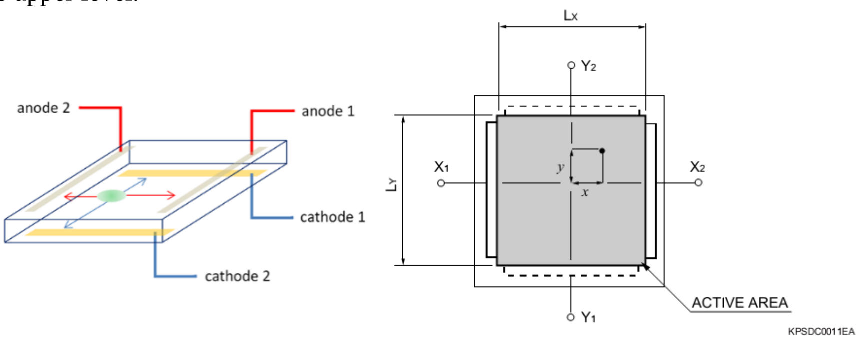


Figure5: LEP bipolar structure of the side effect [3 and 7]

Location of incident light, can be calculated according to the following formula: [3]

$\frac{I_{x2}-I_{x1}}{I_{x1}+I_{x2}} = \frac{2x}{L_x}$ And $\frac{I_{y2}-I_{y1}}{I_{y1}+I_{y2}} = \frac{2y}{L_y}$(11)

Figure 6 shows the equivalent circuit diagram [1]. Here the upper and lower layer resistance are separately modeled just as two variable resistors. The obvious advantages of bipolar instruments can be used to produce relatively high current signals, high position resolution, revealing the perfect location and low distortion. [3]

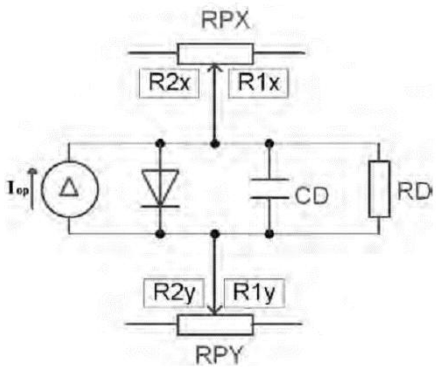


Figure 6: The equivalent circuit of side-effect bipolar detector [1]

4-2-2 quadrupole side effects photodiodes:

According to figure 7, quadrupole side effects photodiode includes a resistive layer on top, four connection on the surface and a common connection below the surface. It means that using them are easier and by placing the connections on the top both electrical connections and placing the detector are easier.

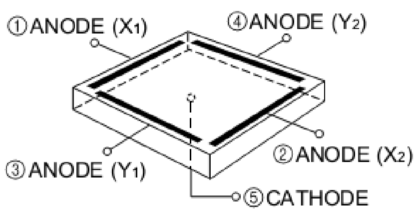


figure 7: LEP structure of side effect quadrupole[3]

The problem in comparison with bipolar disorder, is justifying the connection on the top. According to Figure 8, because of the proximity of the electrodes together, through broad distribution position, there is an interaction between light flows that makes a big distortion in the corners of the zone and is activated by setting the junction, and linear behavior of the detector is improved. [3 and 8]

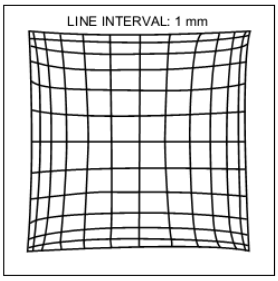


Figure 8: The impact of LEP side effects quadrupole electrodes [3]

Figure 9 shows the equivalent circuit of quadrupole side effect photodiode. Here top layer resistant with four separate resistance, has been replaced. Determine x and y components for both the dipole and quadrupole detector is the same and equations in each direction position is in the same PSD equation.

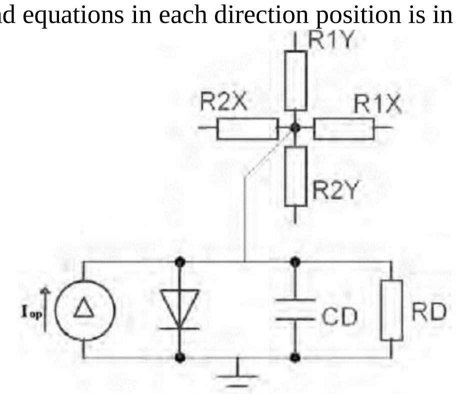


figure 9: Equivalent circuit of quadrupole side effects detector [1]

Quadrupole detectors compared to bipolar detectors are in long-distance and are non-linear positioning and detection error are larger [2]. The high response, low dark current, use more convenient and less bias voltage [3, 4].

4-3 Quadrupole detectors:

According to Figure 2-10, Quad detectors (QD), usually consisting of two or four photodiode elements with a separate anode and cathode that are separated by a small gap about some micron. Optical currents generated in each section are proportional to the intensity of incident light. By comparing the flow of discrete elements, we can calculate the position of the stain toward the center of the detector. Due to the structure of the detector, when the light spot is fully adhered on one part, we cannot determine light spot position in a linear position. In this case, we can only say that the light spot is somewhere on the element. When the light spot is also smaller than the groove between the sections, the light spots cannot be detected. In these cases, using a suitable optical system, focal spot size are focused on sectors [1, 4]. Such apparent instruments are excellent for tracking spots in the center, but to respond to the motion of a circular stains they are non-linear. The reason is that the rate of moving spots is shifted to the percentage of area in adjacent segments that is non-linear [4,1], relating to LEP they are in a better uncertainty and resolution of this situation [2]. Because of less noise, QD have better detector in further distances. [4].

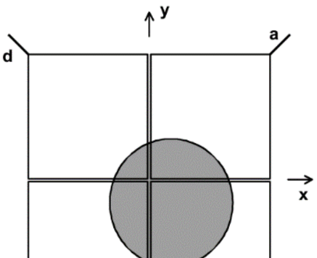


Figure 10: PSD distinct structure or QD [1]

Position of light spot relative to the center of detector can be calculated according to the following formula:

$$y = \frac{(I_a+I_d)-(I_c+I_b)}{I_a+I_b+I_c+I_d} \quad x = \frac{(I_a+I_b)-(I_c+I_d)}{I_a+I_b+I_c+I_d} \quad (12)$$

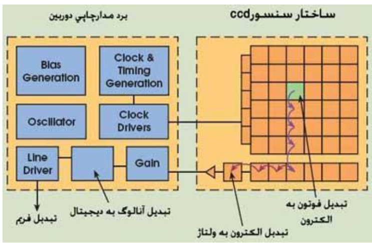
Two major differences of LEP and QD, are the impact of spot size on the measurement area and size of the sensors and as a result, transitional characters in this range and also differences in noise levels accuracy. In case of QD, the sensor size is determined by the size of the light spots and the effects of QD depends on optical radiation of light spot spatial distribution and is nonlinear for uniform light spot

While in LEP, the size of the sensor depends on the size of the active region and is independent of spot size and linear transformation parameters. LEP have inherently more flexibility in noise than QD. In the absence of background of QD, it has 40 times resolution is better than LEP, while in sunlight, the background is reversed but the accuracy of QD is still better than LEP [4]. In addition to these detectors, standard pixel detectors such as CCD and CMOS sensors can be used to determine the position. In such cases, position of light spots is determined by comparing the signals from all the pixels. Their advantage is that they are easier to remove the effect of stray light and simultaneous measurement of multiple light sources is possible. Their disadvantage is that they require more sophisticated electronic equipment to read and determine the position of the light spot and output processor image [1].

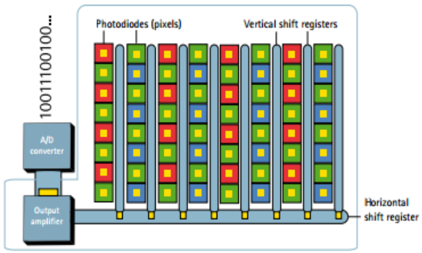
5- CCD Sensors:

5-1 Introduction:

Charged Coupled Device (CCD) invented in 1970 by Boyle and Smith. Since then significant articles are written about physics, construction and performance of CCD. To form the image on the array of light-sensitive screen, CCD requires an optical system. Arrays need Clock signals and driver. It includes a series of analog pulses that is indicative of the intensity of the scenes in a series of discrete locations. CCD is an analog shift register by which the analog signal (electric charge) moved by controlling the clock signal in the adjacent classes. The SSD can be used as a memory or delay in analog signal. According to figure 11 (a) and (b), CCD is an array of some capacitor and by emitting light on them, each can store the quantity of electric charge in itself proportion to the intensity of incoming light. Upon the completion of the exposure (and closed shutter) using the clock pulse, each capacitor can transfer its contents to the adjacent capacitor. This transfer is done in parallel in the arrays and in the last row, the contents of capacitor is read as series and they are inverted to voltage.



11- a) CCD arrays (Writeage.com)



11-b) CCD arrays (9)

The benefits of CCD can be outlined as follows: high quantum efficiency, wide spectral response, low noise and high charge transfer efficiency.

The following table compares the types of detectors.

3. Conclusion

As can be seen from the chart below, according to the types of PSD, strengths and weaknesses, quadrat detectors is suitable for various laser spot tracking.

CCD	PSD			Types of PSD
	LED or continuous or side effect		QD or Separate	Parameters
Less than PSD	More than CCD and Duo-LATERAL	More than CCD	More than LEP or CCD	The speed of Responding
Less than PSD	Better than CCD	Better CCd and TETRA-LATERAL (less than 0.5 micrometer)	Better than CCD or LEP	Resolution or sensitivity
Linear	Nonlinear more than Duo-LATERAL	Excellent linear	nonlinear	Being sensitive to the position of linear or nonlinear
More expensive than PSD	Cheaper than CCD	Cheaper than CCD	Cheaper than CCD	Equipment price
More complicated than CCD	Simpler than CCD	Simpler than CCD	Simpler than CCD	Simple circuit
More complicated than PSD	Easier than CCD and Duo-LATERAL	Easier than CCd	Easier than LEP and CCd	Ease of use
Less influenced	More influenced	More influenced	More influenced	affected by the backlight
ENABLE POSSIBLY	UNABLE	UNABLE	UNABLE	Image processing capability
Less than other types	Less than Duo-LATERAL	Less than QD	LESS	Dark current
Less than other types	Less than Duo - LATERAL	Less than QD	Less	Bias current
Depending on the processor	More than Duo-LATERAL	Uncertainty better than TETRA-LATERAL	Better than LEP	Error localization
Less than other types	More than QD	More than QD	Less than LEP	Noise
There is no dependence	lower dependence than LEP	lower dependence than LEP	Higher dependence than LEP	Dependence on the size and intensity of spots
controllable	Less than QD	Less than QD	More than LEP	Stability to temperature

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