SAP-Series Silicon Geiger Mode Avalanche Photodiode

Description

The SAP-Series is based on a "reach-through" structure for excellent quantum efficiency, extremely low noise and bulk dark current and high gain. They are intended for ultra-low light level applications. This APD can be used in either normal linear mode ($V_R < V_{BR}$) at gains of up to 250 or greater, or in the "Geiger" mode. The Geiger Mode APD can be biased above the breakdown voltage ($V_R > V_{BR}$) to allow detection of single photons. Because of the increase in quantum efficiency, magnetic field immunity, robustness, longer operating lifetime, very good timing properties and reduction in costs, solid-state detectors capable of operating at non-cryogenic temperatures and providing single photon detection capabilities provide attractive alternatives to the photomultiplier tube (PMT).

The APD is hermetically sealed in a modified TO-46 package, or as an option it can be supplied with a one stage TEC in a TO-37 package or with a two stage TEC in a TO-8 package. This enables the APD to be used in a variety of demanding applications including LIDAR, spectroscopy, small signal fluorescence detection and photon counting.

Features

- Linear and geiger mode operation
- Very high quantum efficiency
- Extremely low noise
- 300 and 500 µm diameter active area
- Cooled versions available
- Fiber-coupled versions available

Applications

- LIDAR
- Spectroscopy
- Small signal fluorescence detection
- Photon counting
- Medical

Generic Characteristics at T= 25 °C

	SAP300Xx/SAP500Xx			
	Min	Typ	Max	Units
Wavelength range	400		1100	nm
Peak sensitivity		700		nm

Optical Characteristics

	SAP300Xx			SAP500Xx			
	Min	Typ	Max	Min	Typ	Max	Units
Diameter		300			500		µm
Field of view*							deg
- S2-package		76			81		
- T6-package		147			129		
- T8-package		148			130		

*Approximate full angle for totally illuminated photosensitive surface

Absolute Maximum Ratings

	SAP300Xx/SAP500Xx			
	Min	Typ	Max	Units
Storage temperature	-55		100	°C
Operating temperature*	-40		85	°C
Reverse current Peak value (CW operation)			200	µA
Reverse current Peak value (1 sec. duration)			1	mA
Forward current, I_F at 25 °C Average value (CW operation)			5	mA
Forward current I_F at 25 °C Peak value (1 sec. duration)			50	mA
TEC max voltage - T6 - T8			0.8 1.98	V V
TEC max current - T6 - T8			1.9 1.4	A A
Max total power dissipation			60	mW
Soldering (for 15 sec.)			260	°C

*Extended operation temperature range possible for special design considerations.

Electrical Characteristics at T= 22 °C

	SAP300Sx/SAP500Sx			SAP300Tx/SAP500Tx			
	Min	Typ	Max	Min	Typ	Max	Units
Breakdown voltage, V_{BR} @ I_d= 10 µA		125			125		V
Temperature coefficient of V_{BR} for constant gain @ M = 250		0.35			0.35		V/°C
Detector temperature - T6 - T8		22			 0 -20		°C °C °C
Gain		250			250		
Responsivity @ M = 250 @ 900 nm @ 830 nm		 85 110			 85 110		 A/W A/W
Quantum efficiency @ M = 250 @ 900 nm @ 830 nm		 51 65			 51 65		 % %
Dark current, I_d @ M = 250 - T6 - T8		1000			 200 70		pA pA pA
Noise current, i_n^2 @ M = 250 - T6 - T8		90			 40 20		fA/Hz$^{1/2}$ fA/Hz$^{1/2}$ fA/Hz$^{1/2}$
Capacitance, C_d @ M = 250		3.3			3.3		pF
Rise time, t_r: @ M = 250, RL = 50 Ohms, λ = 830 nm, 10% to 90% points		0.5	0.75		0.5		ns
Fall time, t_r: @ M = 250, RL = 50 Ohms, λ = 830 nm, 90% to 10% points		0.5	0.75		0.5		ns
Dark count rate at 5% photon detection probability (830 nm, case temperature of 22 °C)		10000	15000		5000 (T6) 2000 (T8)		cps cps
Voltage above VBR for 5% photon detection probability (830 nm)		2			2		V
After-pulse ratio at 5% photon detection probability (830 nm) 22 °C		2	15		2		%

01/23 / V13 / ED-IF / lc-apd/sap-series-geiger-mode-apd

Fig. 1: Spectral Response (@ M = 100)

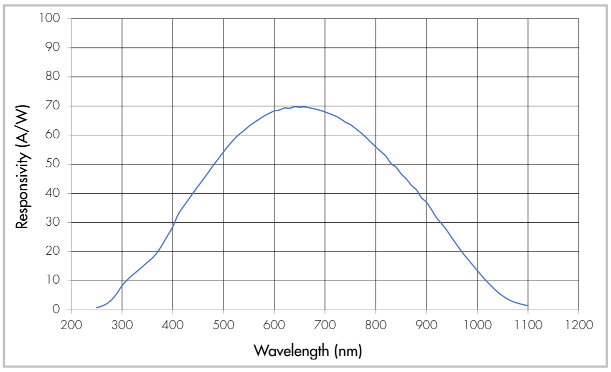


Fig. 2: Quantum Efficiency vs. Wavelength (@ M = 100)

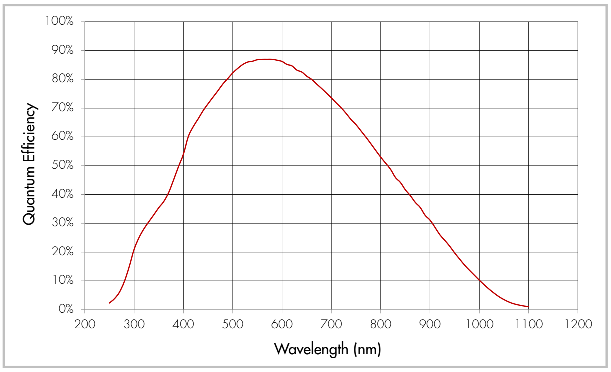


Fig. 3: Typical Dark Current vs. DC Reverse Operating Voltage

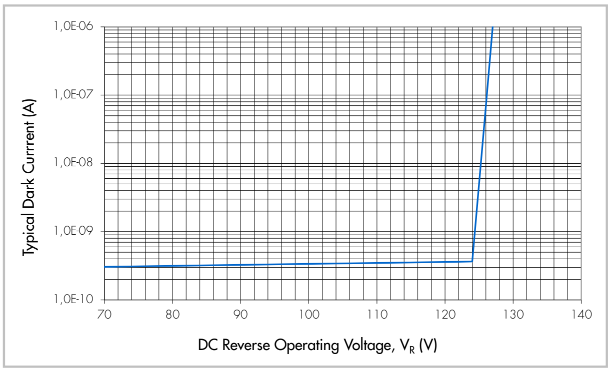


Fig. 4: Typical Noise Current vs. Gain

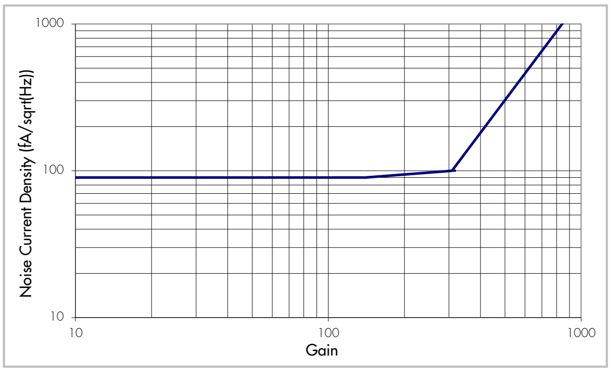


Fig. 5: Typical Dark Count vs. Over Voltage (SAP300T8/SAP500T8)

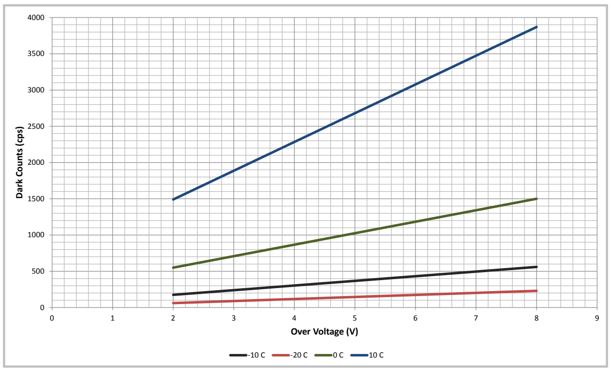
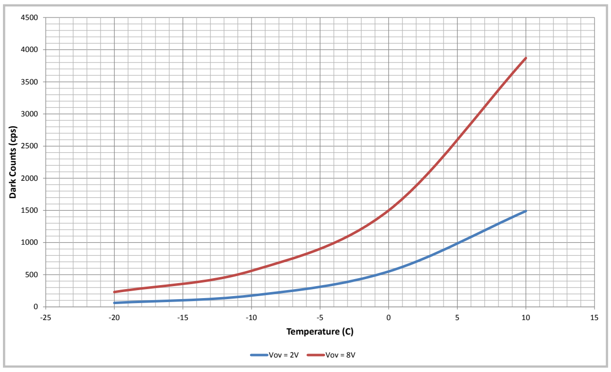
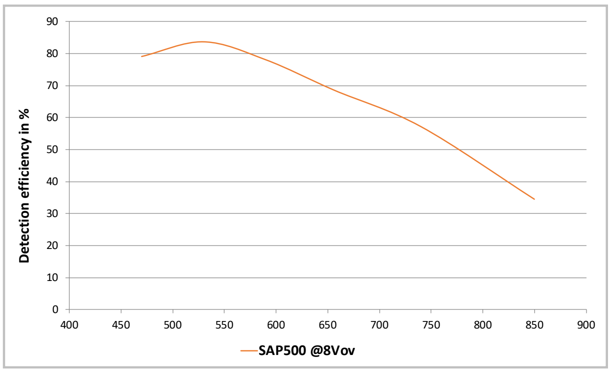


Fig. 6: Typical Dark Count vs. Temperature (SAP300T8/SAP500T8)

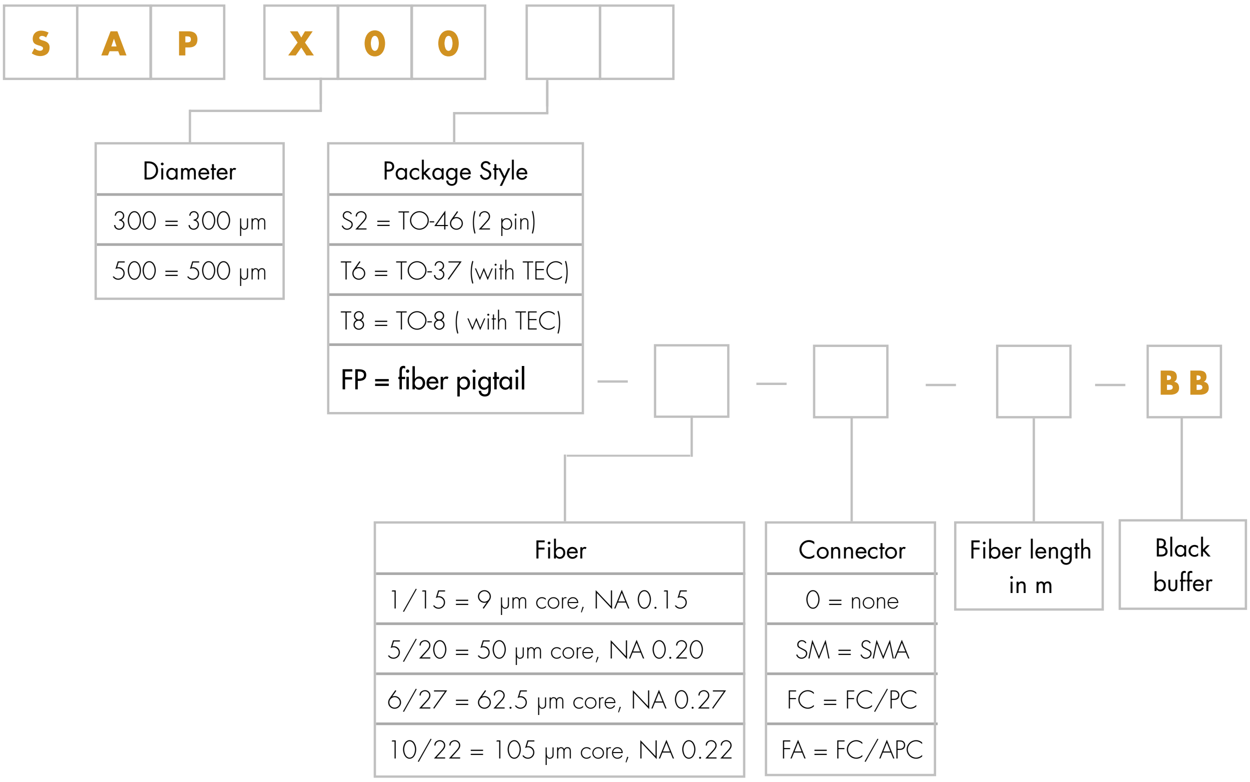


01 / 23 / V13 / ED-IF / lc-apd/sap-series-geiger-mode-apd

Fig. 7: Detection Efficiency vs. Geiger Mode
(SAP-Series @ 8Vov)



Product Number Designations



Diameter
300 = 300 µm
500 = 500 µm

Package Style
S2 = TO-46 (2 pin)
T6 = TO-37 (with TEC)
T8 = TO-8 (with TEC)
FP = fiber pigtail

Fiber
1/15 = 9 µm core, NA 0.15
5/20 = 50 µm core, NA 0.20
6/27 = 62.5 µm core, NA 0.27
10/22 = 105 µm core, NA 0.22

Connector
0 = none
SM = SMA
FC = FC/PC
FA = FC/APC

Fiber length in m

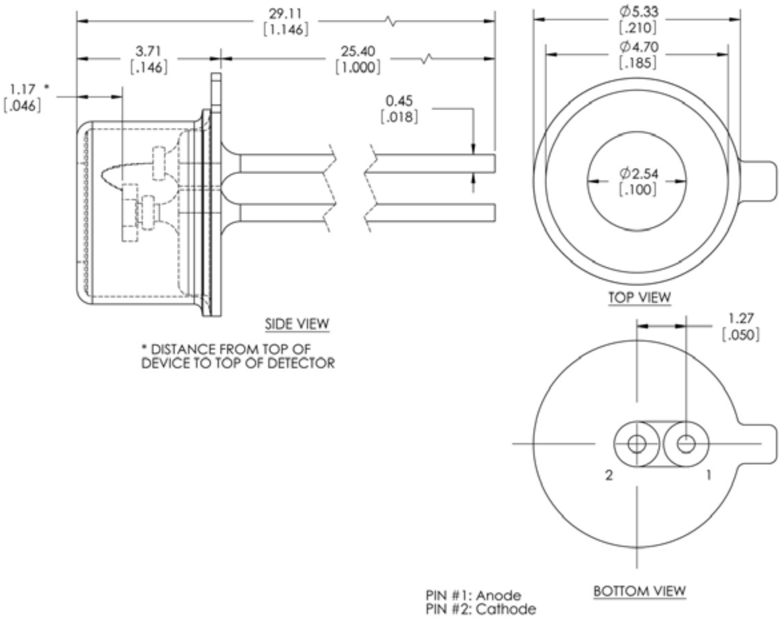
Black buffer

Notes: 1. Other fibers and connectors are available on request

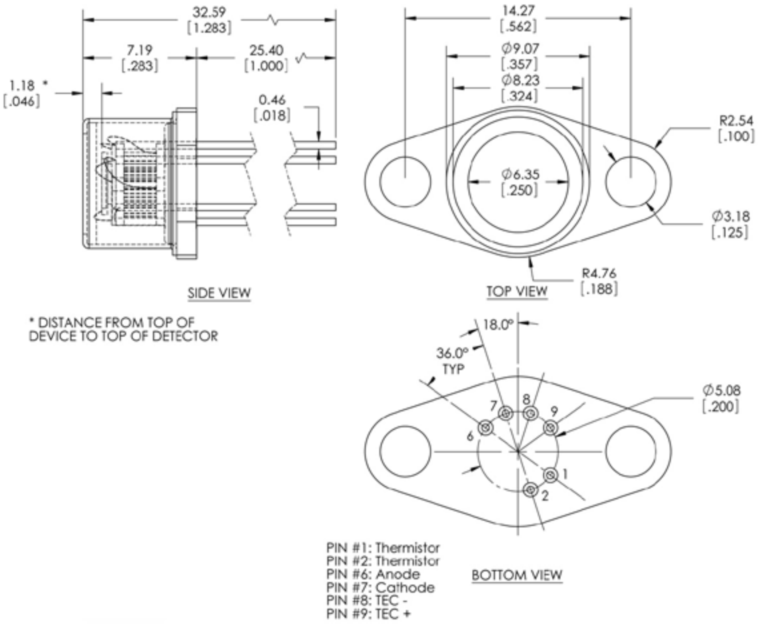
2. BB= black buffer, recommended for low light / photon counting applications

Package Drawings

Package S2 TO-46 (2 pin)

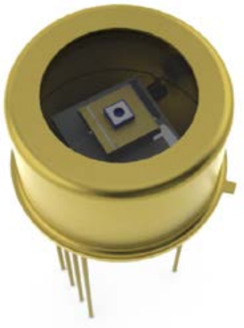


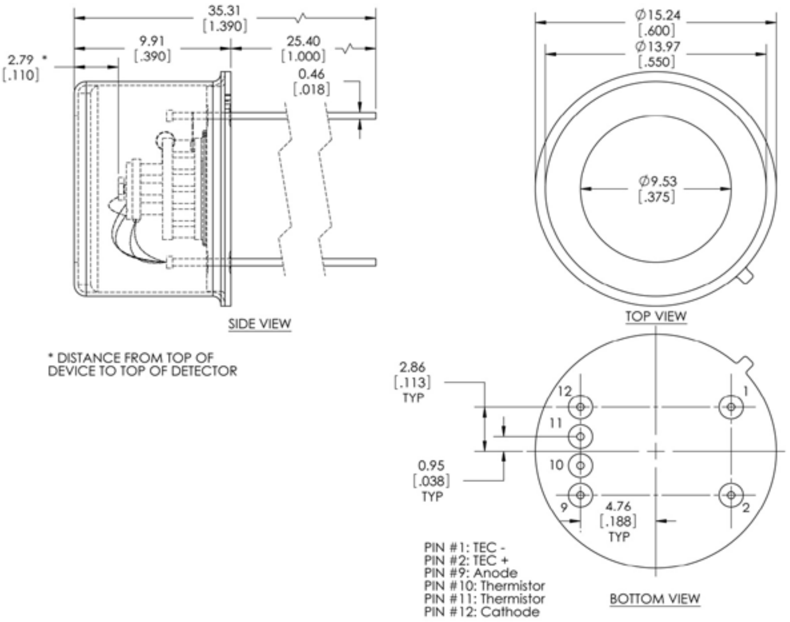
Package T6 TO-37 (with TEC)



Package Drawings

Package T8 TO-8 (with 2 stg. TEC)

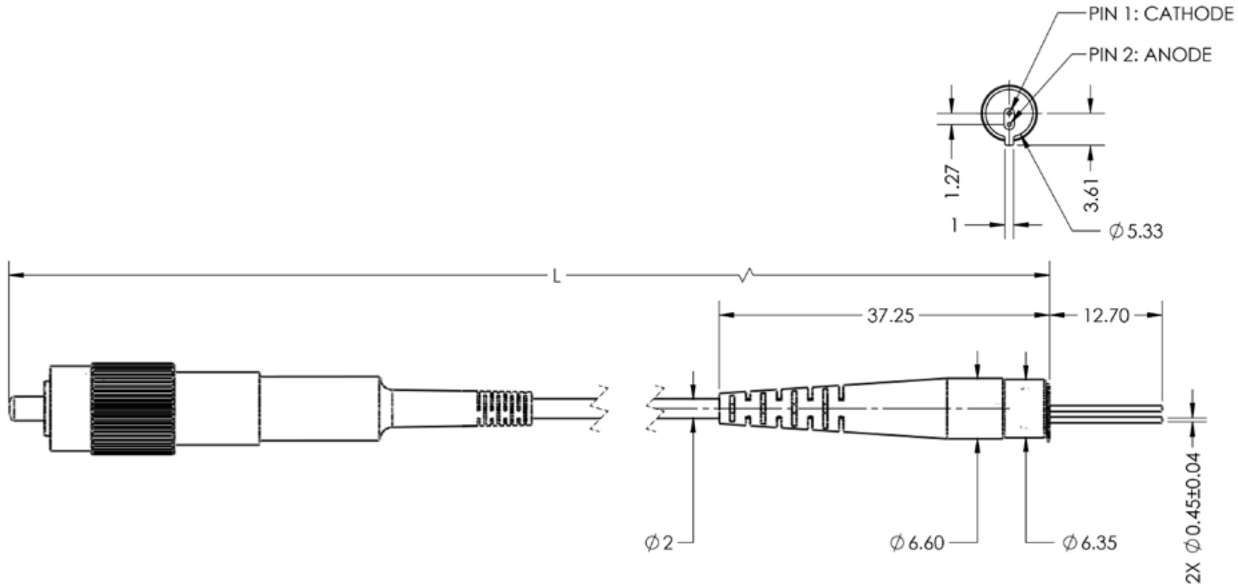




* DISTANCE FROM TOP OF DEVICE TO TOP OF DETECTOR

PIN #1: TEC -
PIN #2: TEC +
PIN #9: Anode
PIN #10: Thermistor
PIN #11: Thermistor
PIN #12: Cathode

Package FP Fiber Pigtail



Cooled Versions

The one stage or two stage thermoelectrically cooled APD can be used for different reasons:

- To reduce the thermal noise for very weak signal detection. The one stage TEC (SAPX00T6) has been design to operate the APD down to 0 °C whereas the two stage TEC (SAPX00T8) version can be operated at – 18 °C when the ambient the ambient temperature is 22 °C.
- To maintain a constant APD temperature irrespective of the ambient temperature. Because APD breakdown voltage decreases with temperature, the TE cooler allows a single operating voltage. Also, this configuration allows constant APD performance over an extended ambient temperature range

The integrated thermistor can be used to monitor the APD temperature and can be used to implement a TE cooler feedback loop to keep the APD at a constant temperature or/and to implement a temperature compensation on the APD bias voltage. A proper heat-sink is required to dissipate the heat generated by the APD and the TE cooler.

Geiger Mode Operation

The SAP-Series can be biased above the breakdown voltage ($V_R > V_{BR}$) to allow detection of single photons. When biased above the breakdown voltage, an avalanche photodiode will normally conduct a large current. However, if the current is such that the current is limited to less than a particular value (about 50 µA for these diodes), the current is unstable and can switch off by itself. The explanation of this behavior is that the number of carriers in the avalanche region at any one time is small and fluctuating wildly. If the number happens to fluctuate to zero, the current must stop. If subsequently remains off until the avalanche pulse is retriggered by a bulk or photo-generated carrier.

Quenching circuits

Single photon detection by an APD assumes reverse bias voltage V_R greater than the „Geiger“ or „breakdown“ voltage VBR. We define "overvoltage" as $V_{over} = V_R - V_{BR}$

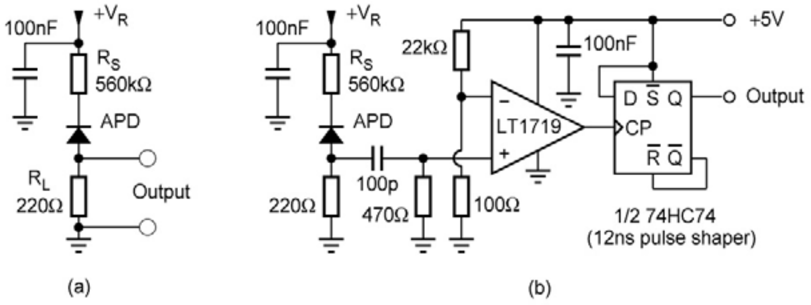


Fig. 7:
(a) the passive quenching circuit,
(b) the same followed by the constant level discriminator and the pulse shaper.

In order to fully assess the characteristics of APDs in Geiger mode one must use some kind of a quenching circuit. In most measurements a simple passive quenching (PQ) circuit shown in Fig. 7(a) can be used, optionally followed by a home-made constant level discriminator (CLD) and a 12 ns pulse shaper as shown Fig. 7(b). A threshold level of the CLD is fixed at 22.5 mV. Due to the capacitive coupling, the circuit in Fig. 7(b) can measure avalanches up to over 2 MHz and is highly immune to the paralyzation effect. If the current limiting resistor R_S is chosen sufficiently large, an avalanche will cease (quench) by itself within a sub-nanosecond timescale.

A condition for successful quenching is that V_{over}/R_S is smaller than the latch current of the given SPAD (Single Photon Avalanche Photodiode). At the same time the voltage across the SPAD will drop somewhat below V_{BR}. After the quench, voltage across the diode recovers towards its initial value following the exponential law with the time constant $\tau = R_S C_{SPAD}$, where C_{SPAD} is the capacitance of the reversely polarized SPAD (plus any parasitic capacitances present in the actual circuit). During the bias recovery SPAD operates at lower overvoltages and features photon detection efficiency lower than the nominal value.

For those measurements for which the long recovery time of the PQ circuit was prohibitive, an active quenching (AQ) circuit is needed. In active quenching, both lowering and restoring of bias voltage are assisted by active electronic components leading to quick recovery and well defined dead time. Neglecting the transition times, in active quenching the SPAD is either completely insensitive to incoming photons or is at its nominal sensitivity. Due to inevitable delays in the electronics, the dead time of an AQ circuit is somewhat longer than the quenching time t_Q during which the SPAD is actually kept below V_{BR}.

Breakdown Voltage and its Thermal Coefficient

When the temperature of a SPAD changes, a variation in operating voltage is required to maintain the same gain.

Dark Counts

In photon counting techniques dark counts cause unwanted noise. The highest tolerable noise in most applications lies between a few hundred Hz and a couple of kHz. For such a low average counting frequency, performance of a SPAD can be assessed quite precisely with the passive quenching circuit.

The SAP-series is optimized to have a low dark-count rate. Cooling to −25 °C can reduce this by a factor of 75, since the dependence of dark-count rate on temperature is exponential.

Dead Time

A explained above, the dead time, which is equal to the sum of the quenching time t_Q plus delays in the electronics, is an inherent feature of the AQ circuit.

Afterpulsing Probability

Afterpulsing in a SPAD is caused by a carriers left over from a previous avalanche, trapped in an impurity and then released at later time. If such a carrier makes its way to the avalanche region it may cause an avalanche which is indistinguishable from a true photon detection. Important parameters for afterpulsing probability are impurity concentration and carrier lifetime. In silicon SPADs afterpulsing is a fast process decaying in about few tens to few hundreds nanoseconds therefore the active quenching is necessary in order to capture afterpulses and measure the afterpulsing probability. We define afterpulsing probability as a probability that an afterpulse will appear after a detection of a photon.

Diving Voltage

Avalanches in Geiger mode appear at a bias voltage greater than V_{BR}. Successful quenching of such avalanches requires lowering the bias voltage somewhat below V_{BR}, namely to V_{BR} – VD where VD is the “diving” voltage. How “deep” the bias voltage must go below the V_{BR} depends on the diode structure, impurities and concentrations of dopands. For most purposes, the best photon counting performance of SPADs is obtained by active quenching. However, since an active quenching circuit can only make a finite (limited) voltage step, SPADs with smaller diving voltages will be able to work at a higher overvoltage and thus, generally, yield a better performance than those with bigger diving voltage.

Timing Resolution (JITTER)

In many applications such as time resolved spectroscopy, quantum communication or range finding, precise timing of photon arrival is essential. For photon counting application, the time of the TTL triggered pulse after detection of a photon, when plotted on a curve, take the FWHM averaged, is the timing resolution or time jitter. The jitter at the half-voltage point is typically the same order of the magnitude as the rise-time. For timing purposes where it is important to have minimum jitter, the lowest possible threshold of rising pulse should be used.

Product Changes

LASER COMPONENTS reserves the right to make changes to the product(s) or information contained herein without notice. No liability is assumed as a result of their use or application.

Ordering Information

Products can be ordered directly from LASER COMPONENTS or its representatives. For a complete listing of representatives, visit our website at www.lasercomponents.com
Custom designed products are available on request.