C30902SH Series Avalanche Photodiode for Linear and Geiger Mode operation

High Responsivity, Low Noise Reach-Through SPAD



Excelitas' C30902SH Avalanche Photodiodes are high speed, large area Silicon APDs that provide high responsivity at low noise. They are specially selected to be used either in Geiger Mode ($V_{op} > V_{BD}$) for detection of single photons or Linear Mode ($V_{op} < V_{BD}$) with Gains up to 250.

Key Features

- Spectral response 400 nm – 1100 nm
- Low Dark Current / Dark Count Rates
- High quantum efficiency of 84% at 800 nm
- SPAD for Photon Counting applications
- Large active area with diameter of 500 µm
- RoHS compliant

Applications

- LiDAR / ToF measurements
- Quantum Communication
- Optical time-domain reflectometer (OTDR)
- Laser scanning

All specifications are referring to an ambient temperature of T_A = 22 °C, λ = 800 nm and a gain of M = 250 unless otherwise specified.

Table 1: Key parameters

Parameter	Symbol	Minimum	Typical	Maximum	Unit
Breakdown Voltage	V_{BD}	185	225	260	V
Spectral Range	Δλ	400		1100	nm
Peak Responsivity	λ_{peak}		800		nm
Quantum Efficiency[1]	QE		84		%

Note 1: Quantum Efficiency is not a directly measureable quantity. The above specified typical parameter is linked to the typical responsivity by $QE = \frac{1240R}{\lambda M}$

Table 2: Ordering Information

Parameter	C30902SH	C30902SH-2	C30902SH-TC	C30902SH-DTC
Reach-Through APD	X			
Geiger Mode SPAD[1]	X			
Flat Glass Window	X			
Active Area Shape	Circular			
Useful Area	0.2 mm^2			
Useful Diameter	0.5 mm			
905 nm Filter		X		
Single Stage TEC[2,4]			X	
Double Stage TEC[3,4]				X
TO-18 package	X	X		
TO-66 flange outline package			X	X

Note 1: This APD is suitable for low-noise operation in linear mode or photon counting in the Geiger mode.
Note 2: The recommended APD operating temperature of the single stage TEC is typically 0 °C.
Note 3: The recommended APD operating temperature of the double stage TEC is typically -20 °C.
Note 4: Adding a TEC to the APD will significantly reduce dark current, dark noise and NEP.

Table 3: Absolute Maximum Ratings

Parameter	Symbol	Condition	Value	Units
Forward Current	I_F	RMS	5	mA
		Single Peak, 1 s	50	
Total Power dissipation	P_{tot}		60	mW
Reverse Current	I_R	RMS	0.2	mA
		Single Peak, 1s	1	
Drive Current TEC	I_{-TC}	RMS	1.8	A
	I_{-DTC}		1.4	
Bias Voltage TEC	V_{-TC}	RMS	0.8	V
	V_{-DTC}		2	
Storage Temperature	T_S		-60 … 100	°C
Operating Temperature	T_{Op}		-40 … 85	

Note 1: Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device.

Note 2: Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Table 4: Electrical Specifications Linear Mode

Parameter	Symbol	Minimum	Typical	Maximum	Units
Recommended Operating Gain	M		250		
Responsivity	R	117	135		A/W
Rise Time / Fall Time[1]	t_r / t_f		0.4		ns
Bandwidth	f_{3dB}		800		MHz
Temperature Coefficient of V_{BD}	$\Delta V/\Delta T$	0.5	0.7	0.9	V/°C
Capacitance	C		1.5	1.8	pF
Dark Current[2]	i_D		7	10	nA
	$i_{D,TC}$		2		
	$i_{D,DTC}$		1		
Dark Noise[3]	i_N		0.1	0.25	pA/√Hz
	$i_{N,TC}$		0.04		
	$i_{N,DTC}$		0.02		
Noise Equivalent Power[4]	NEP		0.74		fW/√Hz
	NEP_{TC}		0.29		
	NEP_{DTC}		0.15		

Note 1: As estimated by $t_{r/f} = \frac{0.35}{f_{3dB}}$

Note 2: Surface (i_{DS}) and bulk (i_{DB}) dark current are contributing to the total dark current by $i_D = i_{DS} + i_{DB}M$.

Note 3: Due to the natural fluctuations of amplified charge carriers the APD will also generate noise when not illuminated. Since the noise characteristics and hence the signal-to-noise ratio (SNR) are depending on the bandwidth (B) and used wavelength (λ) inside the final system the illuminated noise

$$i_{ill} = \sqrt{2qB[i_{DS} + (i_{DB}M^2 + R_0(\lambda)M^2P)F]}$$

needs to be considered. Hence the SNR defines as: $SNR = \frac{i_P^2}{i_{ill}^2} = \frac{(PR_0(\lambda)M)^2}{i_{ill}^2}$ with P the incident optical power in W, $R_0(\lambda)$ the intrinsic (M = 1) responsivity in A/W, q the charge carrier and F the excess noise factor (ENF).
It is not recommended to use approximations like $F = M^x$ as this method gives erroneously results versus actual measurements of an APD, particularly when operated at gains that are differing from the specified gain in the datasheet. The ENF at a certain gain is depending on the k-factor k_{eff}, a material property of the APD, which for the C30902SH series is k_{eff} = 0.02.
For more information see also :
Philippe Bérard, Martin Couture, and Richard J. Seymour "Excess noise factor of front and back-illuminated silicon avalanche photodiode", Proc. SPIE 11388, Image Sensing Technologies: Materials, Devices, Systems, and Applications VII, 113880P (23 April 2020)

$$F(M, k_{eff}) = k_{eff}M + (2 - \frac{1}{M})(1 - k_{eff})$$

Note 4: The NEP is specified in dark conditions as $NEP = \frac{i_N}{R(\lambda,M)}$

Table 5: Optical Specifications C30902SH-2

Parameter	Symbol	Minimum	Typical	Maximum	Unit
Spectral Range	$\Delta\lambda_{905}$	860		960	nm
Responsivity[1]	R_{905}	90	110		A/W
Peak Responsivity	$\lambda_{peak,905}$		905		nm
Quantum Efficiency[1]	QE_{905}		60		%

Note 1: At λ = 905 nm

Table 6: Electrical Specifications Geiger Mode

Parameter	Symbol	Minimum	Typical	Maximum	Units
Recommended Overvoltage	ΔV		20		V
Photon Detection Efficiency[1]	PDE		53		%
Dark Count Rate	DCR		20	80	kcps
	DCR_{TC}		3.3	12	
	DCR_{DTC}		0.6	3	
After-pulse ratio[2,3]	APR		3	10	%

Note 1: The C30902SH can be operated at a substantially higher PDE, refer to Figure 9.

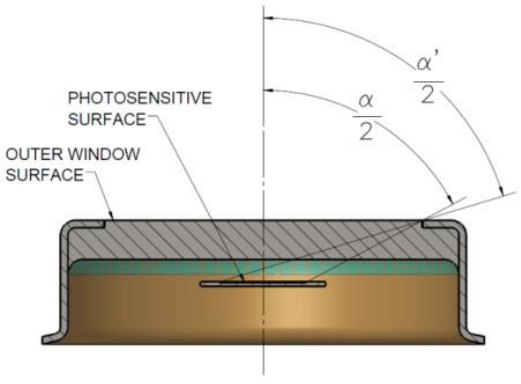
Note 2: After-pulse is strongly dependent on the read-out circuitry used.

Note 3: Measured with an active quenching circuit with a dead-time of 100 ns.
The after pulse is measured from 100 ns to 500 ns.

Table 7: Aperture Specifications

Parameter	C30902SH	C30902SH-2	C30902SH-TC, C30902SH-DTC	Units
Field of view α	90	55	122	°
Field of view α'	114	78	129	°

Figure 1: Field of view definition



VS-383

Figure 2: TO-18 Dimensions C30902SH

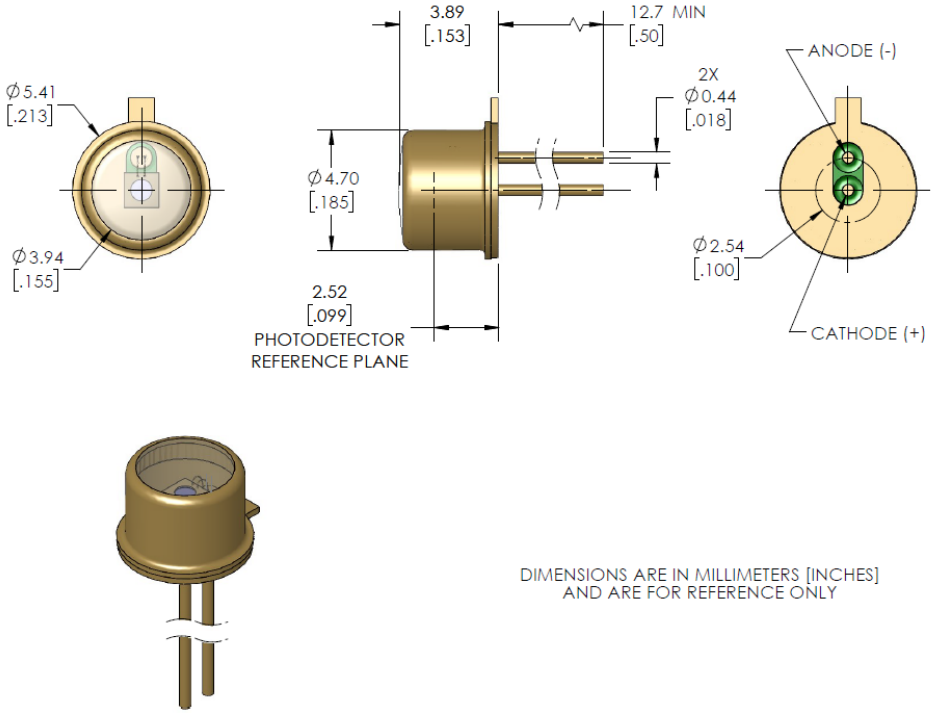


Figure 3: TO-18 Dimensions C30902SH-2

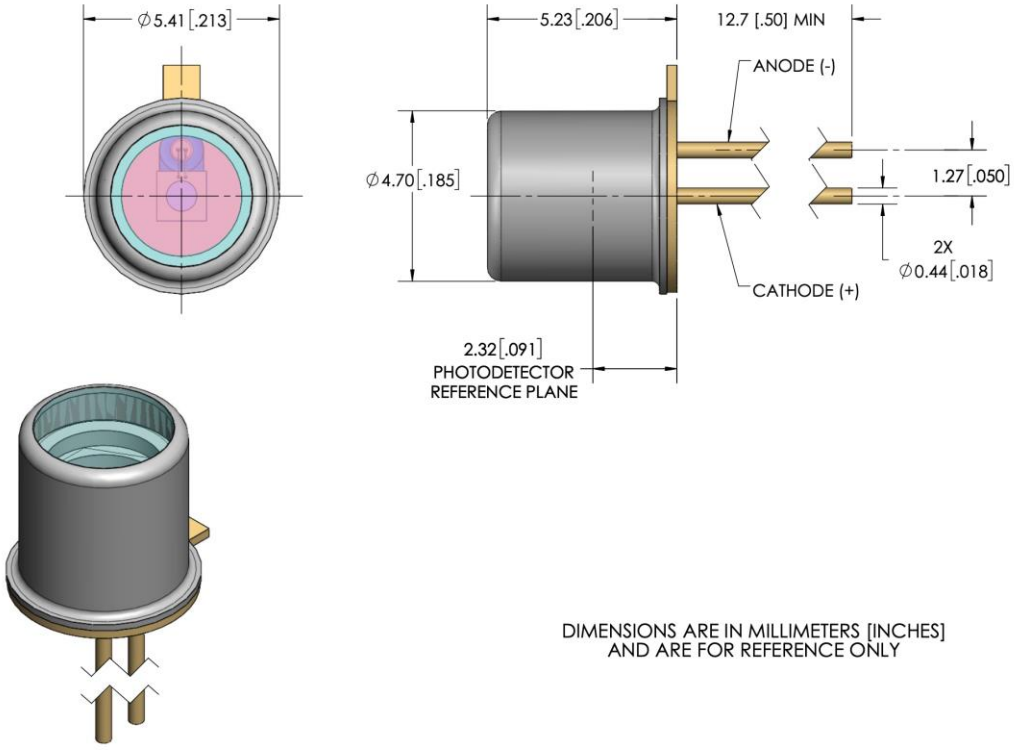
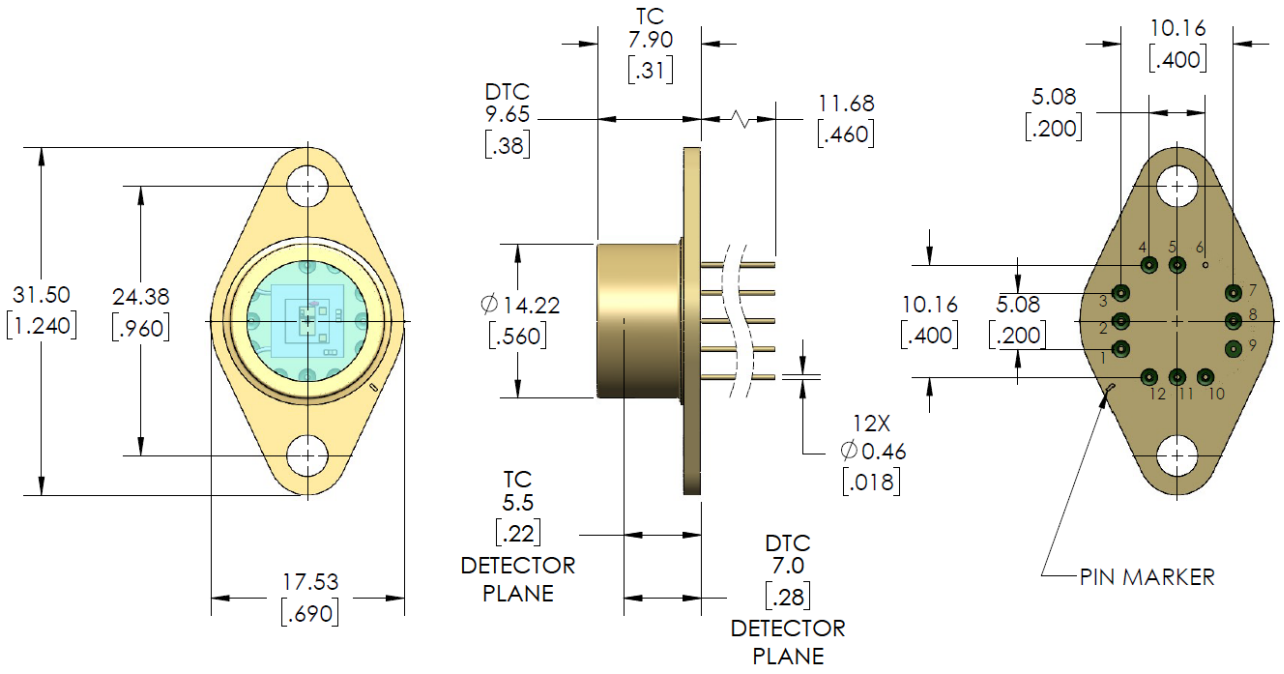
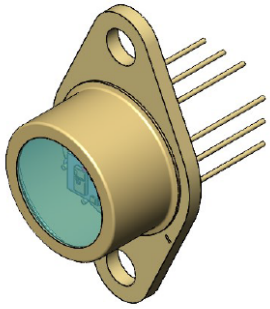


Figure 4: TO-66 Dimensions C30902SH-TC, C30902SH-DTC





PINOUT	
1	NC
2	DETECTOR ANODE
3	NC
4	THERMISTOR
5	THERMISTOR
6	CASE/GND
7	COOLER-
8	N/C
9	COOLER+
10	N/C
11	N/C
12	DETECTOR CATHODE

DIMENSIONS ARE IN MILLIMETERS [INCHES]
AND ARE FOR REFERENCE ONLY

Note 1: The temperature of the Thermistor in Kelvin can be calculated using the following equation:

$$[K] = \frac{\beta}{\ln\left(\frac{R}{r_\infty}\right)}$$

where R is the measured Thermistor resistance in Ω, β = 3200, R_0 = 5100 Ω, $r_\infty = R_0 e^{-\frac{\beta}{T_0}}$ and T_0 = 298.15 K

Note 2: It is recommended to use a PID regulator to operate the TEC.

High Responsivity, Low Noise Reach-Through SPAD

Figure 5: Typical Responsivity

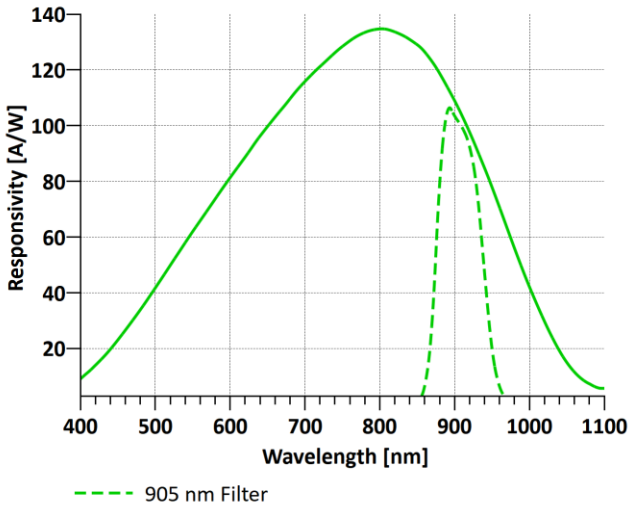


Figure 6: Typical Quantum Efficiency

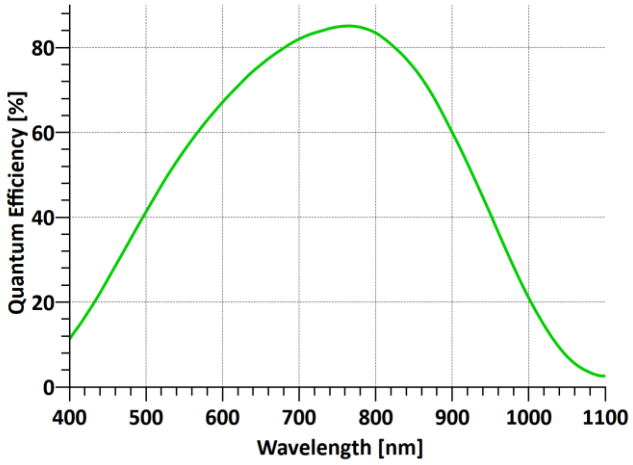


Figure 7: Typical Capacitance

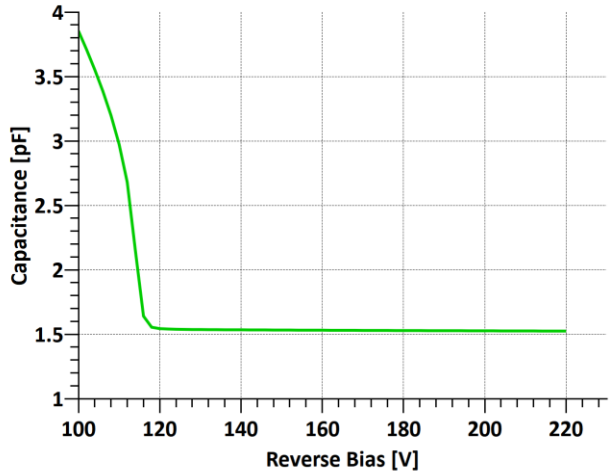
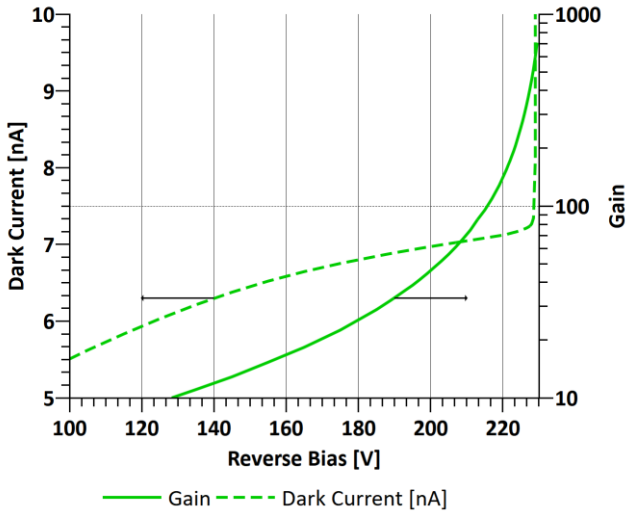


Figure 8: Typical Dark Current and Gain



High Responsivity, Low Noise Reach-Through SPAD

Figure 9: Typical PDE and APR

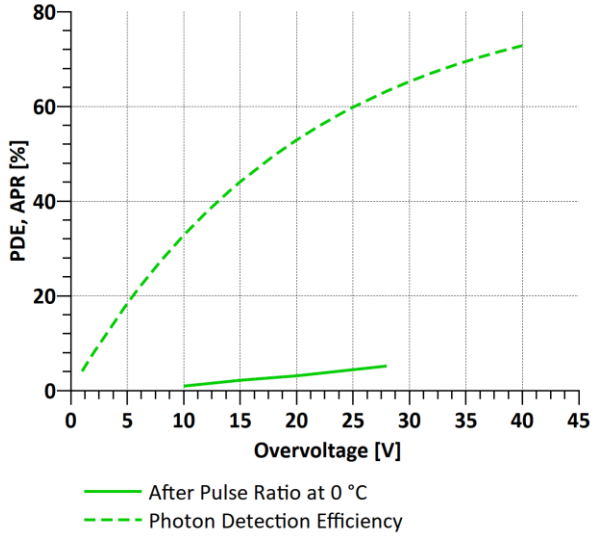


Figure 10: Typical Noise Parameter

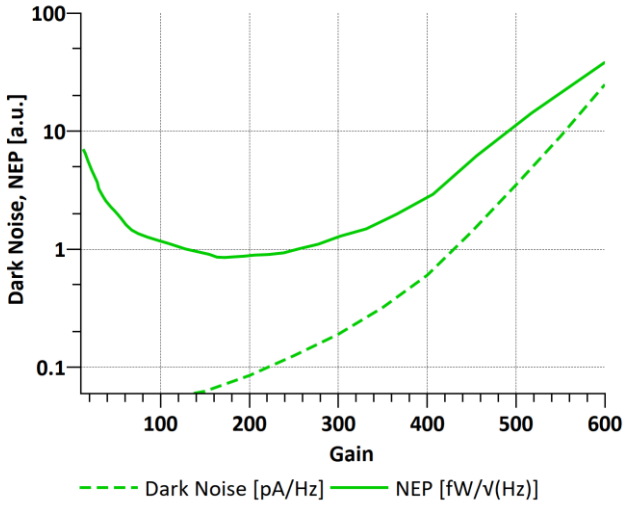


Figure 11: Typical Dark Count Rate

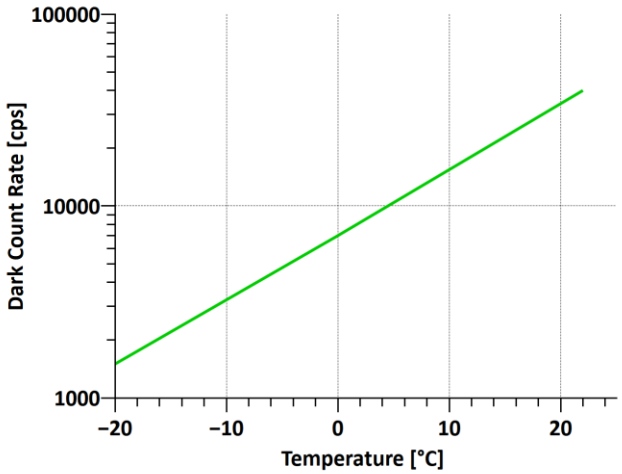
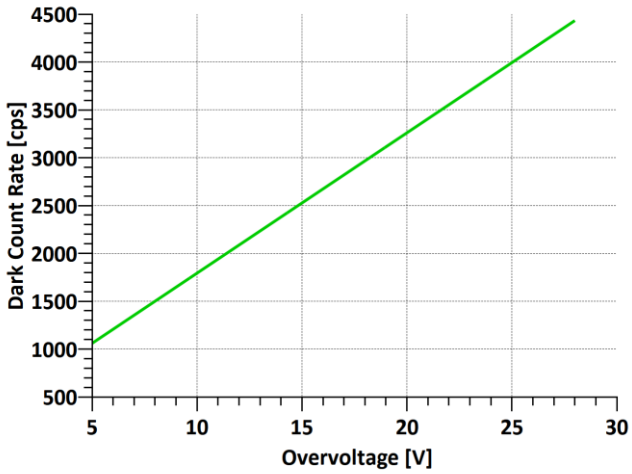


Figure 12: Typical Dark Count Rate at 0°C



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Information

Excelitas' C30902SH family of Silicon SPADs provide extremely low noise and bulk dark-current enabling very high performance data and distance measurements. They are especially well suited for ultra-low light level detection applications (e.g. single photon counting and quantum communication) and intended for use with optical powers less than 1 pW. The C30902SH can be used in either the linear mode ($V_{OP} < V_{BD}$) at typical gains of 250 or greater, or in "Geiger" mode ($V_{OP} > V_{BD}$) with extremely low and stable dark count rates and after pulsing ratios. In this mode, no amplifiers are necessary and single-photon detection probabilities of up to approximately 50% are possible. For even greater performance, these high performance SPADs are available with single or dual-stage thermoelectric coolers.

The responsivity of the APD is independent of modulation frequency up to about 800 MHz. The detector chip is hermetically-sealed behind a flat glass window in a TO-18 package, or TO-66 flange outline when ordered with a TEC. The useful diameter of the photosensitive surface is 0.5 mm.

Thermo-Electric-Cooled Version

TE cooled APDs can be used for multiple reasons. Most applications benefit from using a cooled APD for two reasons:

- To reduce the thermal noise for very small signal detection
- To keep a constant APD temperature at variying ambient temperatures. As the APD breakdown voltage decreases with a decrease in temperature, the TE cooler allows a single operating voltage and hence a constant APD performance over an extended ambient temperature range.

The thermistor located inside the package can be used to monitor the APD temperature, to implement a feedback loop to keep the APD chip at a constant temperature and/or 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

When biased above the breakdown voltage, an avalanche photodiode will normally conduct a large current. However, if the current is limited to less than a particular value (about 50 µA for these diodes), the current is unstable and can swith off by itelf using either "passive" or "active" pulse quenching circuits. Each circuit has application specific (dis-)advantages and hence a detailed description is omitted here.

Testing methods

Excelitas verifies the electro optical specifications on every device. Hence, a specific voltage, V_{OP}, is supplied with each device. When the photodiode is operated at this voltage (at 22 °C), it will meet the electrical specifications shown above. This voltage will be lower than the breakdown voltage V_{BD}.
Visual inspection during fabrication is performed as per our quality standard and failed diodes are removed
Excelitas Technologies is certified to meet ISO-9001 and are designed to meet MIL-STR-883 and/or MIL-STD-750 specifications.

The following parameters are part of Excelitas testing procedures

- Operating Voltage
- Breakdown Voltage
    - C30902SH-TC: additionally at 0 °C
    - C30902SH-DTC: additionally at -20 °C
- Dark Current
- Responsivity @ 830 nm
- Dark Noise
- Geiger Mode Voltage
- Photon Detection Efficiency
- Dark Count Rate

Packaging and shipping

The C3902SH series APDs are shipped in ESD safe plastic trays.

Storage and handling

Excelitas highly recommends to follow the below notes:

- Keep APDs in a ESD controlled environment until final assembly.
- Keep the trays closed until final assembly.
- Remove APDs from tray by using a non-metallic, ESD safe tweezer.

RoHS Compliance

This series of APD diodes are designed and built to be fully compliant with the European Union Directive on restrictions of the use of certain hazardous substances in electrical and electronic equipment.

Warranty

A standard 12-month warranty following shipment applies.

About Excelitas Technologies

Excelitas Technologies is a global technology leader focused on delivering innovative, customized solutions to meet the lighting, detection and other high-performance technology needs of OEM customers.

Excelitas has a long and rich history of serving our OEM customer base with optoelectronic sensors and modules for more than 45 years beginning with PerkinElmer, EG&G, and RCA. The constant throughout has been our innovation and commitment to delivering the highest quality solutions to our customers worldwide.

From aerospace and defense to analytical instrumentation, clinical diagnostics, medical, industrial, and safety and security applications, Excelitas Technologies is committed to enabling our customers' success in their specialty end-markets. Excelitas Technologies has approximately 7,000 employees in North America, Europe and Asia, serving customers across the world.

Excelitas Technologies
22001 Dumberry Road
Vaudreuil-Dorion, Quebec
Canada J7V 8P7
Telephone: (+1) 450.424.3300
Toll-free: (+1) 800.775.6786
Fax: (+1) 450.424.3345

Excelitas Technologies GmbH & Co. KG
Wenzel-Jaksch-Str. 31
D-65199 Wiesbaden
Germany
Telephone: (+49) 611 492 430
Fax: (+49) 611 492 165

Excelitas Technologies Singapore, Pte. Ltd.
8 Tractor Road
Singapore 627969
Telephone: (+65) 6775 2022 (Main number)
Telephone: (+65) 6770 4366 (Customer Service)
Fax: (+65) 6778-1752

Contact us at http://www.excelitas.com/contact

For a complete listing of our global offices, visit www.excelitas.com/locations

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