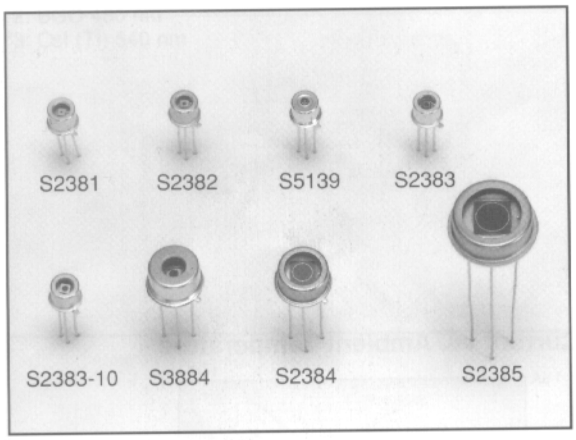
Si APDs (Low-bias Operation Types, for 800 nm Range)

Type No.	Dimensional Outline (P.46, 47)/ Window Material *1	Package	Effective *3 Active Area Size (mm)	Effective Active Area (mm^2)	Spectral Response Range λ (nm)	Peak *4 Sensitivity Wavelength λp (nm)	Photo Sensitivity M=1 λ=800 nm (A/W)	Quantum Efficiency M=1 λ=800 nm (%)
S2381	⑧/K	TO-18	ϕ0.2	0.03	400 to 1000	800	0.5	75
S2382	⑧/K	TO-18	ϕ0.5	0.19	400 to 1000	800	0.5	75
NEW S5139	⑨/L	TO-18	ϕ0.5	0.19	400 to 1000	800	0.5	75
S2383	⑧/K	TO-18	ϕ1.0	0.78	400 to 1000	800	0.5	75
S2383-10 *2	⑧/K	TO-18	ϕ1.0	0.78	400 to 1000	800	0.5	75
S3884	⑬/K	TO-5	ϕ1.5	1.77	400 to 1000	800	0.5	75
S2384	⑭/K	TO-5	ϕ3.0	7.0	400 to 1000	800	0.5	75
S2385	⑱/K	TO-8	ϕ5.0	19.6	400 to 1000	800	0.5	75

*1: Window material K: borosilicarte glass L: lens type borosilicarte glass
*2: The S2383-10 is shielded around the element.
*3: The range that allows muliplication.
*4: Measured with the gain listed in this specification table

Types with suffix (-01: breakdown voltage 80 to 120 V, -02: 120 to 160 V, -03: 160 to 200 V) are available about S2381, S2382, S2383, and S3884.



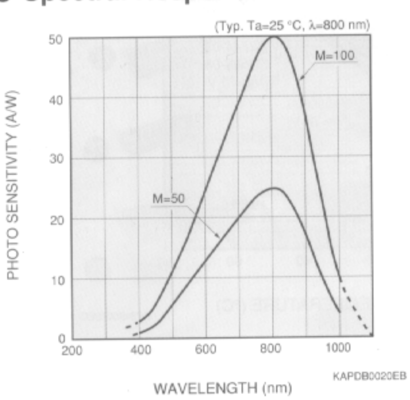
● TE-cooled Si APDs

Parameter	S4315	S4315-01	S4315-02	Unit
APD	S2381	S2382	S2383	–
Effective Active Area*3	ϕ0.2	ϕ0.5	ϕ1.0	mm
Spectral Response Range	400 to 1000			nm
Peak Sensitivity Wavelength*4	800			nm
Cooling Temperature ΔT	35			°C
Package	TO-8			–

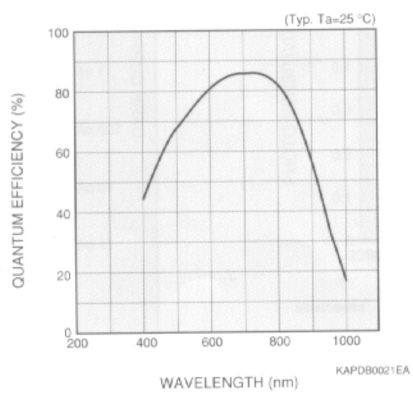
Custom active area types are also available upon request.

To facilitate low-light-level detection using an APD, Hamamatsu provides APD modules that integrate an APD with the operating and signal processing circuits into a compact case. See page 39 for more details.

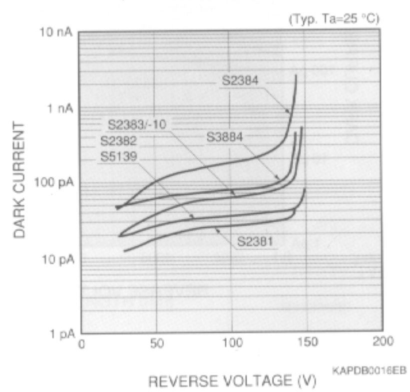
● Spectral Response



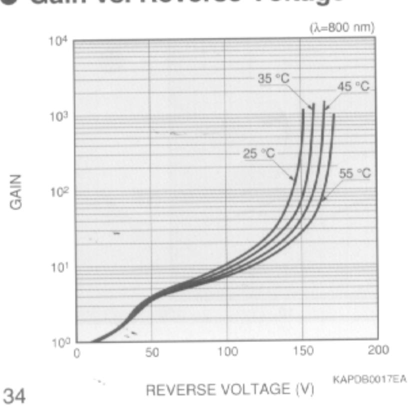
● Quantum Efficiency vs. Wavelength



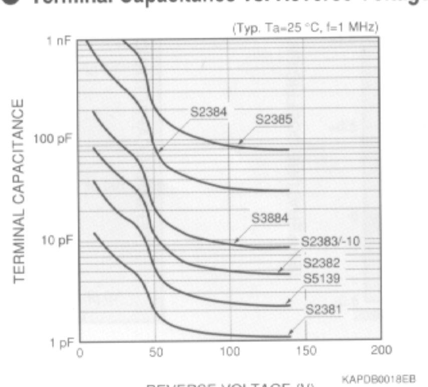
● Dark Current vs. Reverse Voltage



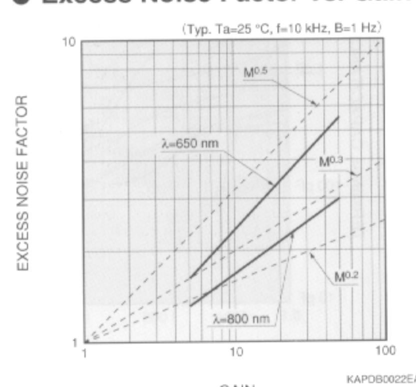
● Gain vs. Reverse Voltage



● Terminal Capacitance vs. Reverse Voltage



● Excess Noise Factor vs. Gain

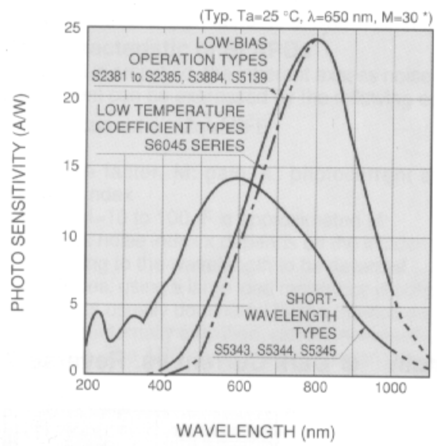


(Unless otherwise noted, Typ. Ta=25 °C)

Breakdown Voltage VBR ID=100 µA (V)		Temperature Coefficient of VBR	Dark Current *4 ID (nA)		Cut-off *4 Frequency fc RL=50 Ω	Terminal *4 Capacitance Ct	Excess *4 Noise Figure x	Gain M	Absolute Maximum Ratings		Type No.
									Operating Temperature Topr	Storage Temperature Tstg	
Typ.	Max.	(V/°C)	Typ.	Max.	(MHz)	(pF)	λ=800 nm	λ=800 nm	(°C)	(°C)	
150	200	0.65	0.05	0.5	1000	1.5	0.3	100	–20 to +85	–55 to +125	S2381
			0.1	1	900	3					S2382
											S5139
			0.2	2	600	6					S2383
											S2383-10
			0.5	5	400	10					S3884
			1	10	120	40		60			S2384
			3	30	40	95		40			S2385

Comparison of Hamamatsu Si APD Characteristics

● Spectral Response



* Measured with a reverse bias voltage that provides a gain of 30 when light at 650 nm wavelength enters the APD.

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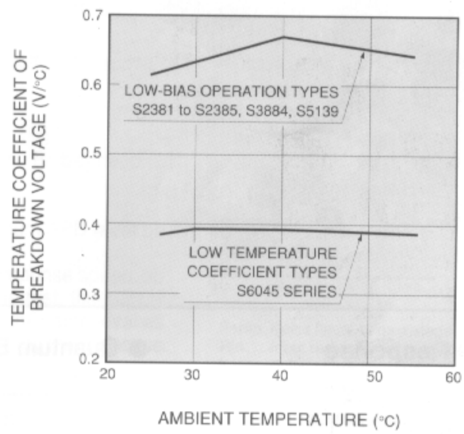
● Temerature Coefficient of Breakdown Voltage vs. Ambient Temperature



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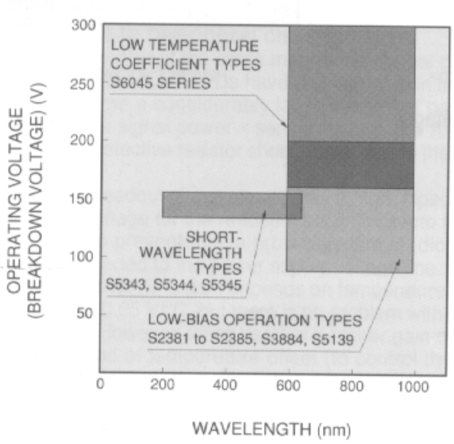
● Operating Voltage (Breakdown Voltage) vs. Wavelength



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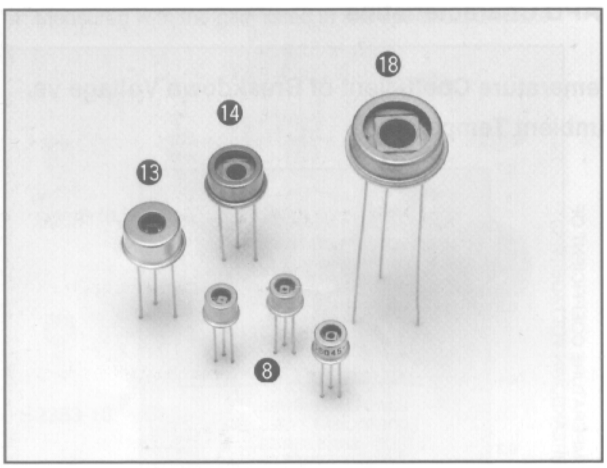
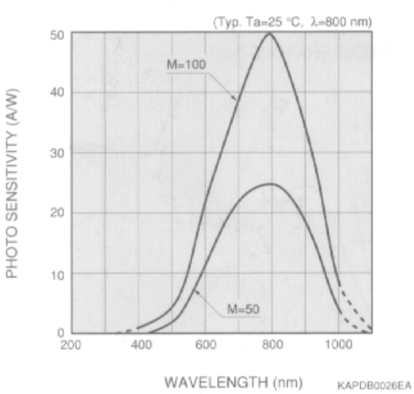
Si APDs (Low Temperature Coefficient Types, for 800 nm Range)

Type No.	Dimensional Outline (P.46, 47)/ Window Material *1	Package	Effective *2 Active Area Size (mm)	Effective Active Area (mm^2)	Spectral Response Range λ (nm)	Peak *3 Sensitivity Wavelength λp (nm)	Photo Sensitivity M=1 λ=800 nm (A/W)	Quantum Efficiency M=1 λ=800 nm (%)
S6045-01	8/K	TO-18	ϕ0.2	0.03	400 to 1000	800	0.5	75
S6045-02			ϕ0.5	0.19				
S6045-03			ϕ1.0	0.78				
S6045-04	13/K	TO-5	ϕ1.5	1.77				
S6045-05	14/K		ϕ3.0	7.0				
S6045-06	18/K	TO-8	ϕ5.0	19.6				

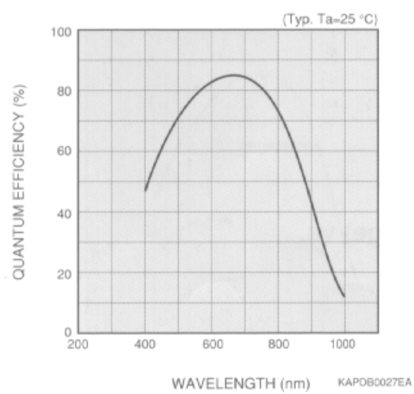
*1: Window material, K: borosilicate glass
*2: The range that allows multiplication.
*3: Measured with the gain listed in this specification table



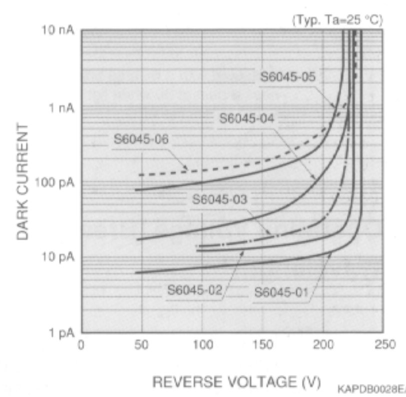
● Spectral Response



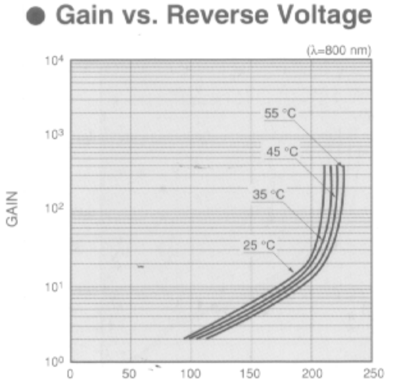
● Quantum Efficiency vs. Wavelength



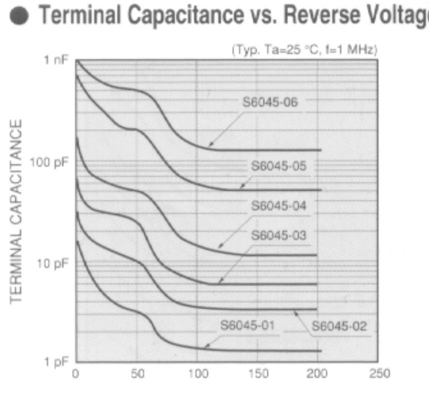
● Dark Current vs. Reverse Voltage



● Gain vs. Reverse Voltage



● Terminal Capacitance vs. Reverse Voltage



(Unless otherwise noted, Typ. Ta=25 °C)

Breakdown Voltage V_{BR} I_D=100 µA (V)		Temperature Coefficient of V_{BR}	Dark Current *3 I_D (nA)		Cut-off *3 Frequency fc R_L=50 Ω	Terminal *3 Capacitance Ct	Excess *3 Noise Figure x	Gain M	Absolute Maximum Ratings		Type No.
									Operating Temperature Topr	Storage Temperature Tstg	
Typ.	Max.	(V/°C)	Typ.	Max.	(MHz)	(pF)	λ=800 nm	λ=800 nm	(°C)	(°C)	
200	300	0.4	0.05	0.5	1000	1.5	0.3	100	-40 to +85	-55 to +125	S6045-01
			0.1	1	900	3					S6045-02
			0.2	2	600	6					S6045-03
			0.5	5	350	12					S6045-04
			1	10	80	50		60			S6045-05
			3	30	35	120		40			S6045-06

Characteristics of Si APDs

● Advantage of the APDs

When using a semiconductor photodetector for low-light-level measurement, it is necessary to take overall performance into account, including not only the semiconductor photodetector characteristics but also the readout circuit (operational amplifier) noise.

When a silicon photodiode is used as a photodetector, the lower detection limit is usually determined by the readout circuit noise because photodiode noise level is very low. This tendency becomes more abvious when the higher frequency of signal to be detected.

This is because the high-speed readout circuit usually exhibits larger noise, resulting in a predominant source of noise in the entire circuit system. In such cases, if the detector itself has an internal gain mechanism and if the output signal from the detector is thus adequately amplified, the readout circuit can be operated so that its noise contribution is minimized to levels equal to one divided by gain (1/10 th to 1/100 th).

In this way, when the lower detection limit is determined by the readout circuit, use of an APD offers the advantage that the lower detection limit can be improved by the APD gain factor to a level 1/10 th to 1/100 th of the lower detection limit obtained with normal photodiodes.

● Noise characteristic of Si APDs

When the signal is amplified, the inherent excess noise resulting from current fluctuation in the avalanche multiplication process is also generated. This noise current can be expressed by the following equation:

$$\text{Shot noise current} = \sqrt{2qI_L M^2 FB}$$

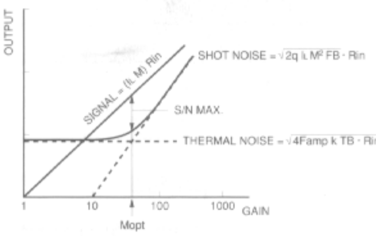
where

F: excess noise factor, M: gain, I_L: photocurrent at M=1, q: electron charge, B: bandwidth, x: excess noise index

In the range of M=10 to 100, F is approximated M^x.

Since the excess noise index x depends on the incident light wavelength, the optimum APD must be selected according to the wavelength to be detected.

In PIN photodiodes, using a large load resistance is not practical since it limits the response speed, so the circuit noise is usually dominated by the thermal noise of the photodiode. In contrast, the gain of an APD, which is internally amplified, can be increased until the shot noise reaches the same level as the thermal noise. The APD can therefore offer an improved S/N ratio without impairing the response speed.



Famp: Noise figure of next-stage amplifier
Rin : Input resistance of next-stage amplifier
k : Boltzmann's constant
T : Absolute temperature

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● Spectral response characteristics of APDs

The spectral response characteristics of the APD are almost the same as those of normal photodiodes if a bias voltage is not applied. When a bias voltage is applied, the spectral response curve will change slightly. This means that the gain changes depending on the incident light wavelength. This is because the penetration depth of light into the silicon substrate depends on the wavelength so that the wavelength absorption efficiency in the light absorption region differs depending on the APD structure. It is therefore important to select a suitable APD.

To allow selection of spectral response characteristics, Hamamatsu provides two types of Si APDs: the S2381 series and S6045 series for near infrared detection and the S5343 series for light detection at shorter wavelengths.

● Temperature characteristics of gain

APD gain varies with temperature. For example, when an APD is operated at a constant bias voltage, the gain decreases with increasing temperature. Therefore, in order to obtain a constant output, it is necessary to vary the bias voltage according to the APD temperature or to keep the APD at a constant temperature.

In the S2381 series, the temperature coefficient of the bias voltage is nearly equal to that of the breakdown voltage which is typically 0.65 V/°C at a gain of 100. Hamamatsu also provides the S6045 series APDs which are designed to have an improved temperature coefficient (0.4 V/°C typical).

● Connection to peripheral circuits

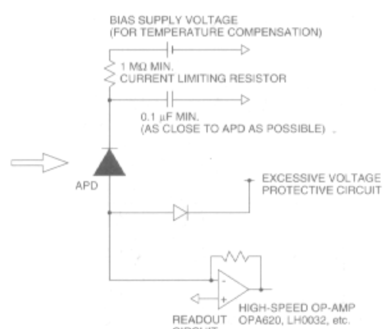
APDs can be handled in the same manner as normal photodiodes except that a high bias voltage is required. However the following precautions should be taken because APDs have an internal gain mechanism and are operated at a high voltage.

① APDs consume a considerably large amount of power during operation, which is given by the product of the signal power × sensitivity (e.g. 0.5 A/W at 800 nm) × gain × bias voltage. To deal with this, a protective resistor should be added to the bias circuit or a current limiting circuit should be used.

② A low-noise readout circuit usually has a high impedance, so if an excessive voltage higher than the supply voltage for the readout circuit flows into the readout circuit, the first stage tends to be damaged. To prevent this, a protective circuit (diode) should be connected so that excessive voltage is diverted to the power supply voltage line.

③ As stated above, APD gain depends on temperature. The S2381 series has a typical temperature coefficient of 0.65 V/°C, but there is no problem with using the APD at a gain of around M=30 and 25 °C±3 °C. However, when used at a higher gain or wider temperature range, it is necessary to use some kind of temperature offset (to control the bias voltage according to temperature) or temperature control (to maintain the APD at a constant temperature).

④ When detecting low-level light signals, the detection limit can be determined by the shot noise of background light. If background light enters the APD, then the S/N ratio may deteriorate due to the shot noise. As a countermeasure for minimizing background light, use of an optical filter, improving laser modulation or restricting the field of view is necessary.



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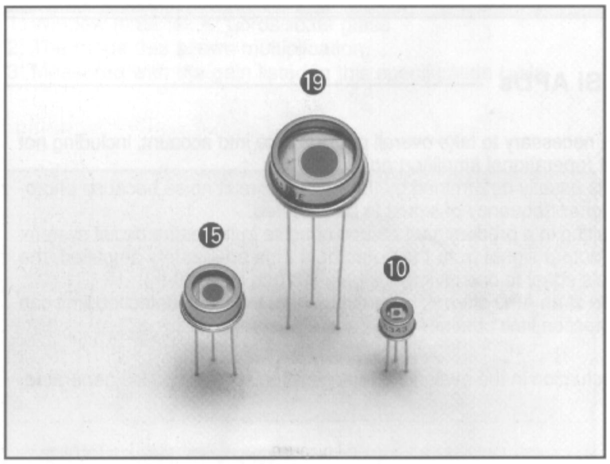
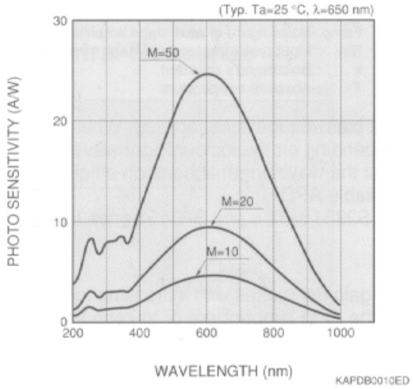
Si APDs (Short-wavelength Types)

Type No.	Dimensional Outline (P.47, 48)/ Window Material *1	Package	Effective *2 Active Area Size (mm)	Effective Active Area (mm²)	Spectral Response Range λ (nm)	Peak *3 Sensitivity Wavelength λp (nm)	Photo Sensitivity M=1 λ=620 nm (A/W)	Quantum Efficiency M=1 λ=620 nm (%)
S5343	⑩/U	TO-18	ϕ1.0	0.78	200 to 1000	620	0.42	80
S5344	⑮/U	TO-5	ϕ3.0	7.0				
S5345	⑲/U	TO-8	ϕ5.0	19.6				

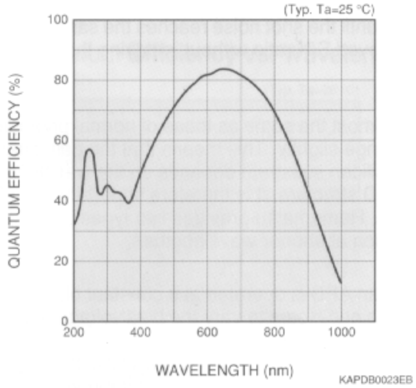
*1: Window material, U: UV glass window
*2: The range that allows multiplication.
*3: Measured with the gain listed in this specification table



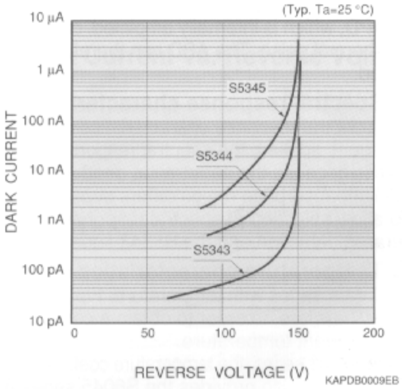
● Spectral Response



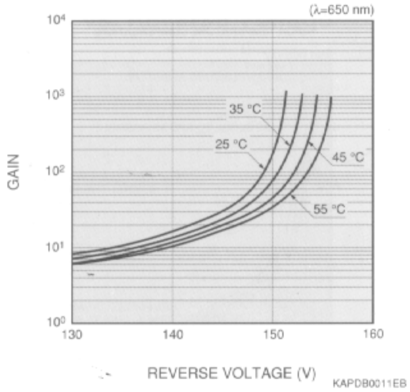
● Quantum Efficiency vs. Wavelength



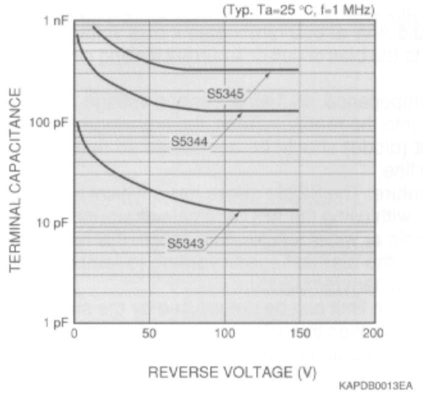
● Dark Current vs. Reverse Voltage



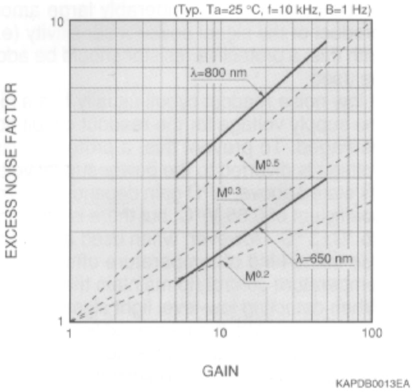
● Gain vs. Reverse Voltage



● Terminal Capacitance vs. Reverse Voltage



● Excess Noise Factor vs. Gain

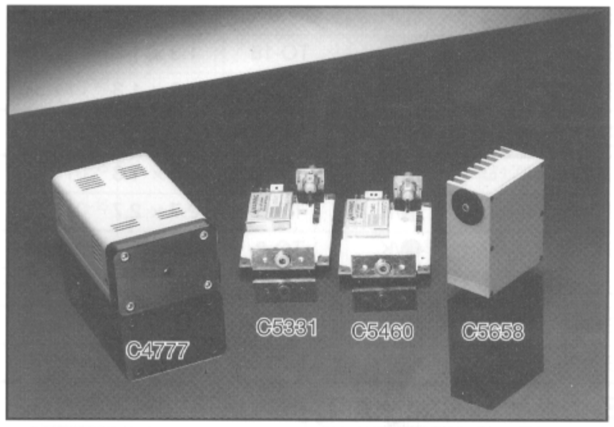


(Unless otherwise noted, Typ. Ta=25 °C)

Breakdown Voltage V_{BR} I_D=100 μA (V)		Temperature Coefficient of V_{BR}	Dark Current *3 I_D (nA)		Cut-off *3 Frequency fc R_L=50 Ω	Terminal *3 Capacitance Ct	Excess *3 Noise Figure x	Gain M	Absolute Maximum Ratings		Type No.
									Operating Temperature Topr	Storage Temperature Tstg	
Typ.	Max.	(V/°C)	Typ.	Max.	(MHz)	(pF)	λ=650 nm	λ=650 nm	(°C)	(°C)	
150	200	0.14	1	10	250	15	0.28	50	−20 to +60	−55 to +100	S5343
			20	100	25	120					S5344
			300	1000	8	320					S5345

APD Modules

The APD modules are high-sensitivity, high-speed O/E converters, consisting of an APD, low-noise amplifier, and bias power supply, integrated into a compact case. These modules enable light detection with an excellent S/N ratio several ten times higher than that obtained with PIN photodiodes. These modules are ideally suited for evaluation and production of light detection systems using APDs.



FEATURES

- **High sensitivity, high S/N ratio, high stability**
- **Easy handling**
- **Compact and lightweight**
- **Low cost**
- **Suitable for evaluation of APD**

Feature/Application	Type No.	Effective *2 Active Area (mm)	Cut-off Frequency Low	Cut-off Frequency High	Photoelectric Sensitivity (V/W)	Minimum Detection Limit	Temperature Stability of Gain (25 °C±10 °C)	Supply Voltage
Standard Types (for NIR) *4								
Peak sensitivity wavelength: 800 nm	C5331	φ1.5	4 kHz	100 MHz	4.50×10^4 *5	3 nWr.m.s *5	±2.5 %	+5 V
· Evaluation of APD	C5331-01	φ0.2	4 kHz	100 MHz	7.50×10^4 *5	3 nWr.m.s *5		
· Spatial light transmission	C5331-02	φ0.5	4 kHz	100 MHz	7.50×10^4 *5	3 nWr.m.s *5		
· Optical rangefinder	C5331-03	φ1.0	4 kHz	100 MHz	6.75×10^4 *5	3 nWr.m.s *5		
· Optical communication	C5331-04	φ3.0	4 kHz	80 MHz	2.30×10^4 *5	4 nWr.m.s *5		
· Laser Radar	C5331-05	φ5.0	4 kHz	50 MHz	0.75×10^4 *5	5 nWr.m.s *5		
Standard Types (for short wavelength) *4								
Peak sensitivity wavelength: 620 nm	C5331-11	φ1.0	4 kHz	100 MHz	2.70×10^4 *6	5 nWr.m.s *6	±2.5 %	+5 V
· Film scanner	C5331-12	φ3.0	4 kHz	40 MHz	1.40×10^4 *6	11 nWr.m.s *6		
· Laser monitoring	C5331-13	φ5.0	4 kHz	20 MHz	0.77×10^4 *6	10 nWr.m.s *6		
High-sensitivity Types								
Low-light-level detection · Bar code reader	C5460	φ1.5	DC	10 MHz	1.50×10^6 *5	800 pWr.m.s *5	±2.5 %	±12 V
· Fluorescence measurement · Particle counter	C5460-01	φ3.0	DC	100 kHz	1.50×10^8 *5	5 pWr.m.s *5		
High-speed Type								
Detection of high-speed response light · OTDR, Optical communication	C5658	φ0.5	1 MHz	1 GHz	2.50×10^5 *7	16 nWr.m.s *7	±5.0 %	+12 V
TE-cooled Type								
Stable detection of light	C4777	φ0.5	10 kHz	100 MHz	5.00×10^5 *7	0.8 nWr.m.s *7	±1.0 %	±15 V +5 V
· Scientific measurement	C4777-01	φ3.0	DC	5 kHz	1.25×10^9 *8	0.2 pWr.m.s *8		

*4: Integrated optical fiber connector types are also available.
*5: M=30, λ=800 nm
*6: M=30, λ=620 nm
*7: M=100, λ=800 nm
*8: M=50, λ=800 nm