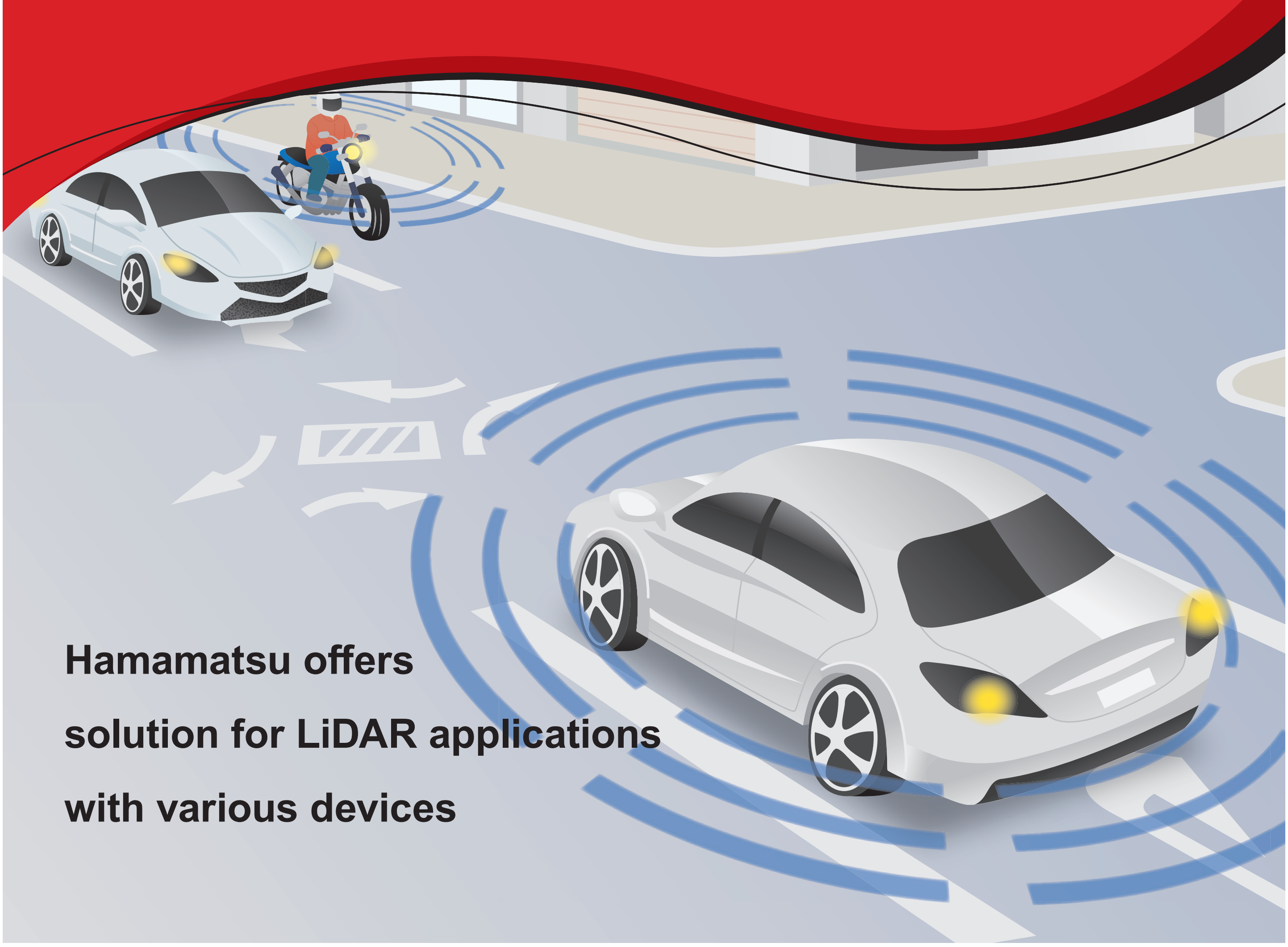
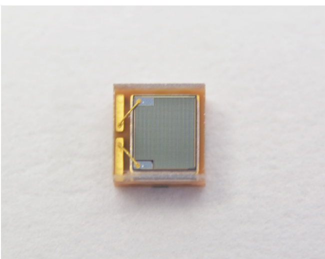
Mar. 2023

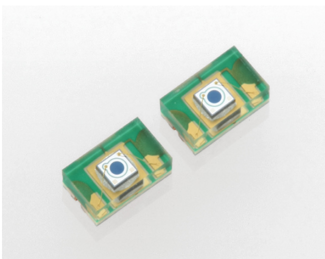
Photodetectors for LiDAR



Hamamatsu offers solution for LiDAR applications with various devices

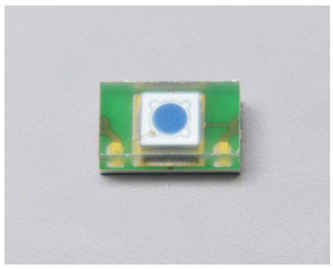


MPPC®
(multi-pixel photon counter)



APD

Photosensor with front-end IC



PIN photodiode

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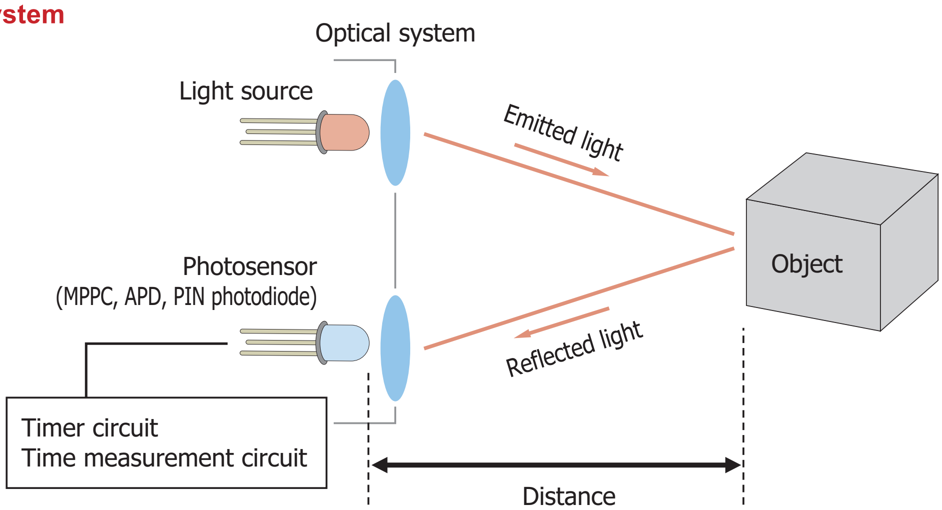
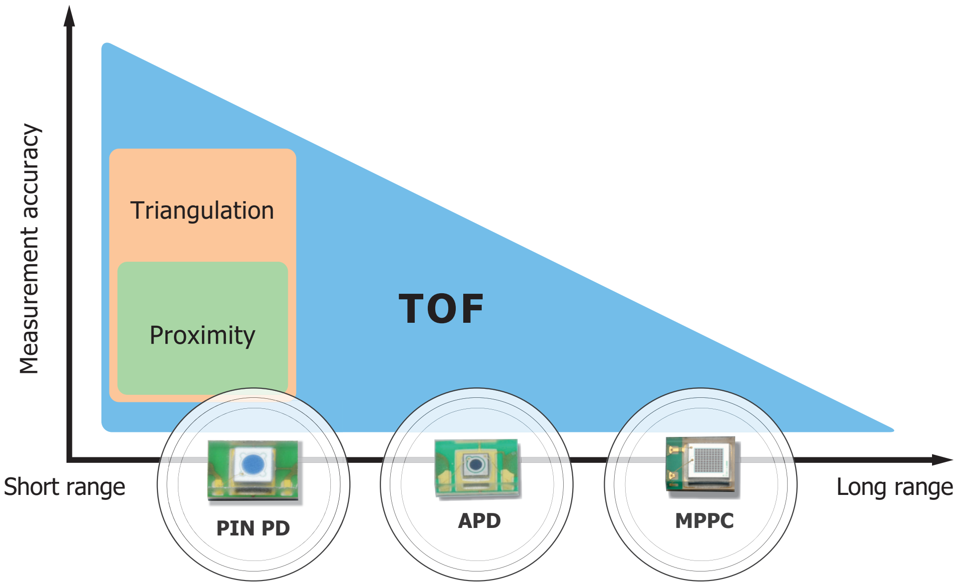
What is Time of Flight (TOF)?

One of the methods to measure distance is time of flight (TOF).
A direct TOF system calculates the distance by measuring the time for light emitted from a light source to be reflected at the target object and received by a photosensor. The system can be configured by combining a sensor, such as an MPPC, APD, or PIN photodiode, a timer circuit, and a time measurement circuit.
Used in combination with a pulse modulated light source, the direct TOF system can obtain distance information by calculating the phase information of the light emission and reception timing.
Other known distance measurement methods include the proximity method and triangulation distance measurement method. These methods are used to measure relatively close distances. In comparison, the TOF method allows long distance measurement. Depending on the selected device, a wide range of distances, from short to long distances, can be measured.

TOF system



Photosensors for TOF



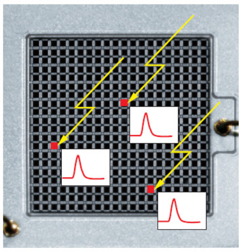
Detector demands for LiDAR applications

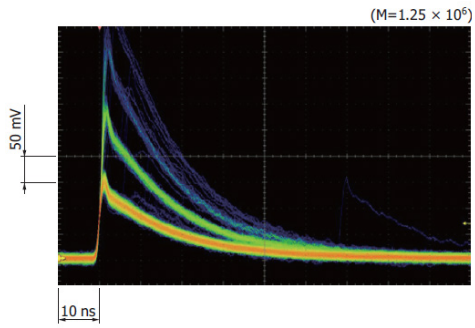
- High sensitivity, Low noise
- Usable under strong ambient light condition
  - Especially in automotive application
- Usable under wide temperature range
- Mass productivity and low cost
- High speed response
- Wide dynamic range
  - From a distance black target (very weak reflected light) to nearby shiny target (too much reflected light)
- Array capability

Comparison

MPPC® (multi-pixel photon counter)

The MPPC is one of the devices called silicon photomultipliers (SiPM). It is a device using multiple APD pixels operating in Geiger mode. Although the MPPC is essentially an opto-semiconductor device, it has excellent photon-counting capability and can be used in various applications for detecting extremely weak light at the photon counting level.
It is the latest of the light-receiving element which will easily obtain multiplication factor of 10^5 to 10^6.
As for the distance meter, a treat of background light becomes more important. For the simplest distance meter, the minimum reception level is the background light intensity. That makes it important to use an optical band-pass filter. Good S/N is obtained in the high-impedance readout circuit. The simplification of the readout circuit enables a total low-cost rangefinder system.





Suitable for:

- Long range measurement
- Direct TOF
- Array / Large area
- Low cost

APD

It is widely used as a highly sensitive light-receiving element for rangefinder.
By electron multiplication, it will be able to increase the S/N until the shot noise limit.
In many cases, the minimum reception level is determined by the shot noise of background light. For this reason, gains from 10 to several tens is often used in rangefinders. It will be possible to capture the distance of distant target than in the case of PIN photodiode. In order to reduce the shot noise due to the background light, it is used in conjunction with an optical band-pass filter. As a readout circuit, a transimpedance amplifier is used as well as a PIN photodiode.

Suitable for:

- Long range
- Direct TOF
- High ambient light with band-pass filter

PIN photodiode

The PIN photodiode is the simplest photosensor for rangefinders and has a wide dynamic range. Sensitivity is stable and uniform. It can also be used under strong background light. A transimpedance amplifier is used as a readout circuit. The minimum receive level is determined by the noise of the readout circuit.

Suitable for:

- Short range
- Array / Large area
- Direct TOF
- High ambient light
- Low cost
- Low voltage operation

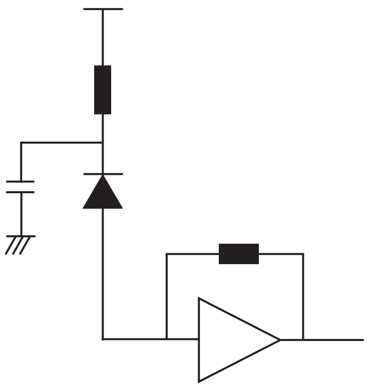
Comparison chart

Parameter	MPPC®	APD	PIN photodiode
Range	Long	Middle	Short
Accuracy	High	High	High
Readout circuit	Simple	Complex	Complex
Operation voltage	to several tens of V	100 to 200 V	to 10 V
Gain	10^5	10 to 100	1
Temperature characteristics	Good	Fair	Excellent
Response time	Fast	Medium	Medium
Ambient light immunity	Medium	Medium	High
Array	Suitable	Suitable	Suitable
Gap	Narrow	Wide	Wide
Uniformity	Good	Depends on the size	Good

Readout circuits

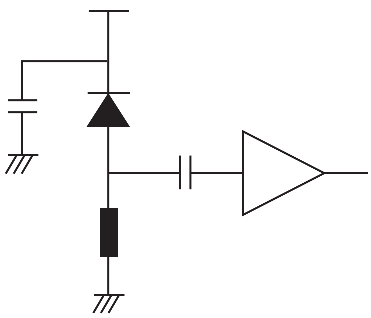
Transimpedance amplifier

Suitable for MPPC, APD and PIN photodiode



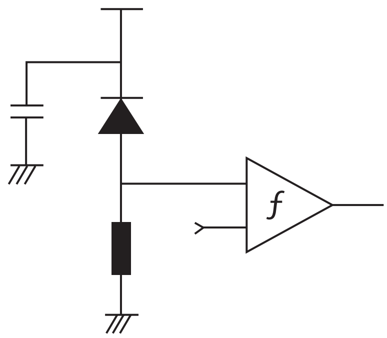
Resistor with high frequency amplifier

Suitable for MPPC

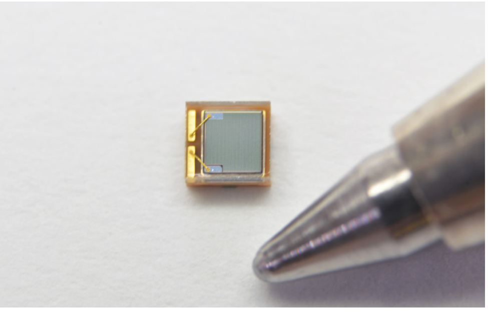


Resistor with high comparator

Suitable for MPPC



MPPC®



The S15639-1325PS is MPPC for LiDAR applications. The feature is high sensitivity to near-infrared wavelengths.
The photon detection efficiency (PDE) at near-infrared wavelengths, often used in LiDAR, has been improved over our previous products.

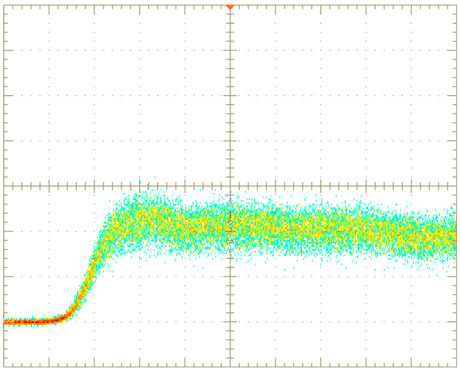
Specifications (Typ. Ta=25 ℃)

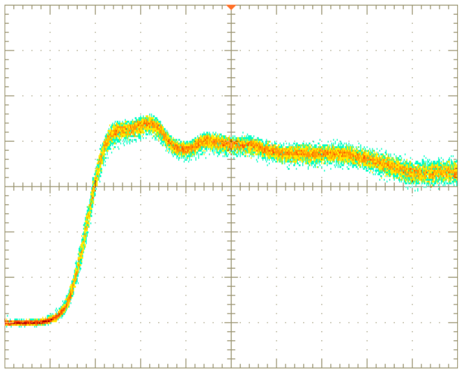
Parameter		Symbol	S15639-1325PS	Unit
Package		-	Surface mount type	-
Operating temperature		Topr	-40 to +105	℃
Storage temperature		Tstg	-40 to +125	℃
Soldering condition		-	260 ℃ max., 3 times	-
Effective photosensitive area (H × V)		-	1.1 × 1.3	mm
Pixel pitch		-	25	μm
Number of pixels / channels		-	2120	pixels
Window material		-	Silicone resin	-
Window refractive index		-	1.57	-
Spectral response range		λ	400 to 1000	nm
Peak sensitivity wavelength		λp	660	nm
Photon detection efficiency (λ=905 nm)		PDE	9	%
Breakdown voltage		V_{BR}	42	V
Recommended operating voltage		V_{op}	V_{BR} + 14	V
Dark count	Typ.	-	700	kcps
	Max.	-	2100	
Crosstalk probability		-	6	%
Afterpulse probability		-	< 1	%
Terminal capacitance		Ct	42	pF
Gain		M	1.7×10^6	-
Temperature coefficient of recommended operating voltage		ΔTVop	66	mV/℃

Features of MPPC

Feature 1 Waveform is very stable even under saturated conditions.

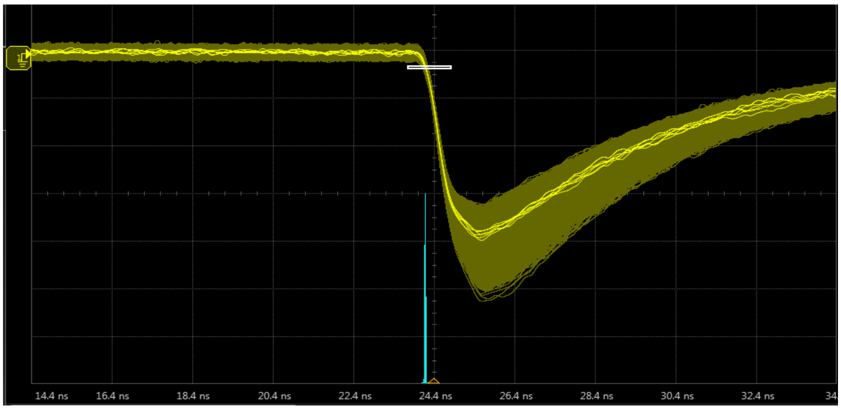
Weak light input	Saturated light input





MPPC
Photosensitive area: 105 × 105 μm
Pixel size: 15 μm

Feature 2 Quick rise time, Low jitter: 15.16 ps(σ)



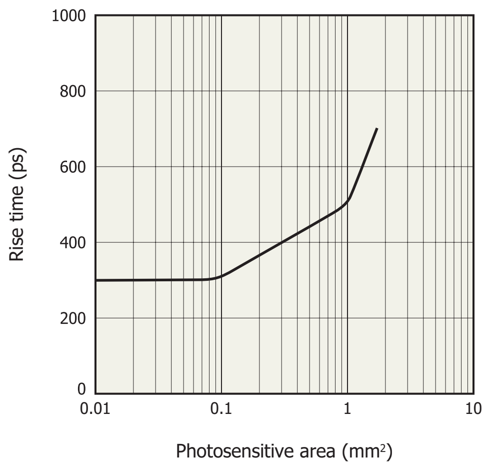
MPPC S12571-015P
Photosensitive area: 1 × 1 mm
Pixel size: 15 μm

Feature 3 **Fast rise time, even large photosensitive area such as 1 mm^2**

Feature 4 **Bigger output is obtained with small photosensitive area MPPC.**

- Suitable for array configuration
- It can be used without any amplifier.

Rise time vs. active area



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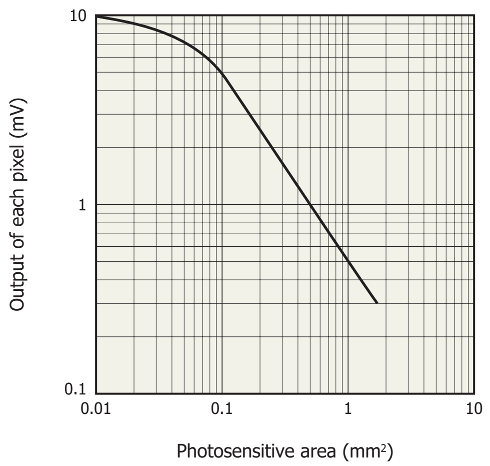
Output of each pixel vs. active area



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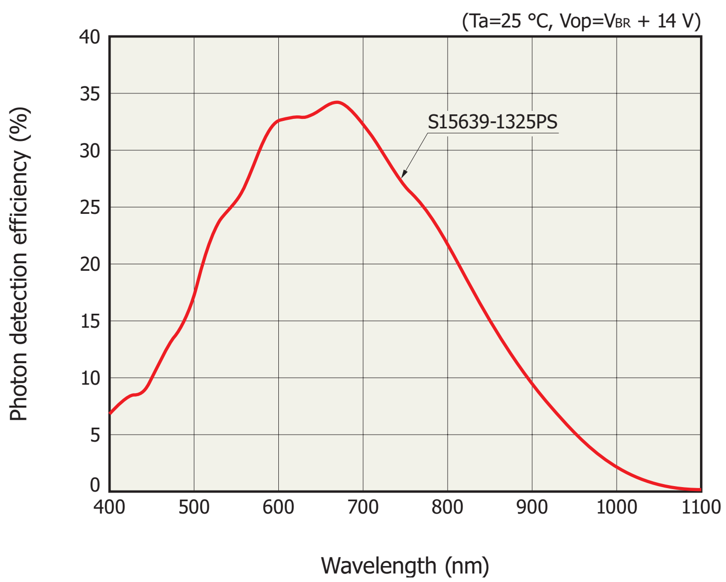
Feature 5 **High sensitivity in 905 nm band**

- High sensitivity to near infrared wavelengths that rangefinders use
- The efficiency falls in infrared reigion, but MPPC still has higher sensitivity compared with APD because of its 10^5 gain.

PDE vs. wavelength



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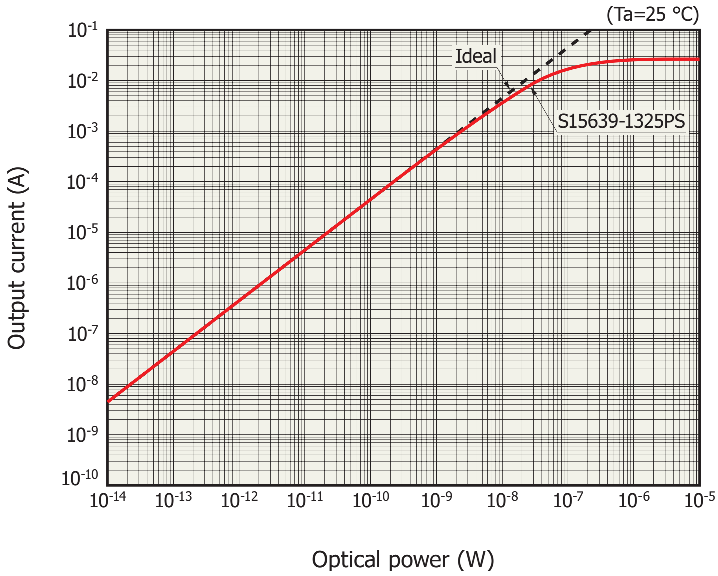
Feature 6 Wide dynamic range and background light suppression

Linearity



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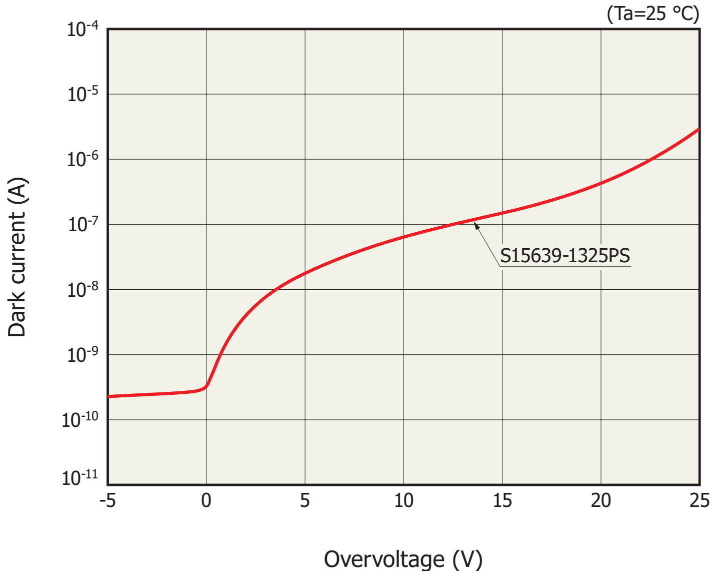
Feature 7 Low operating voltage and wide voltage range

Dark current vs. overvoltage



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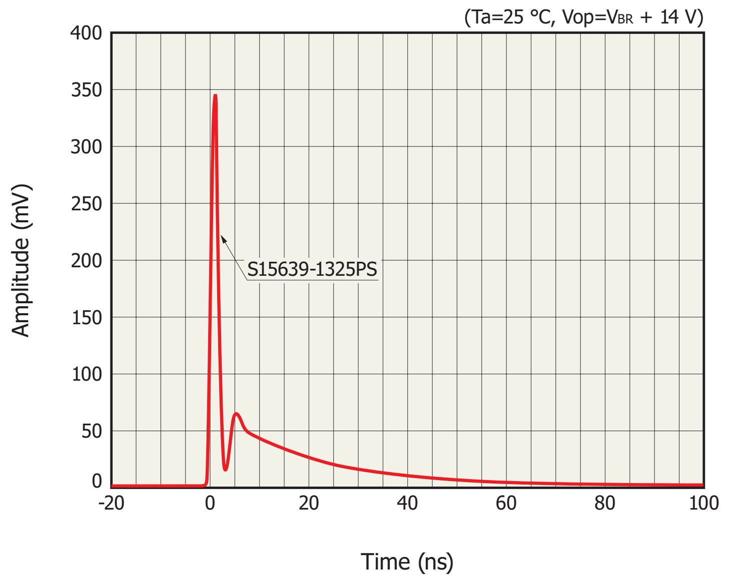
Feature 8 Fast rise time and recovery time

- Fast rise time and recovery time due to the small capacitance
- High repetition rate contributes to wide dynamic range

Rise time and recovery time



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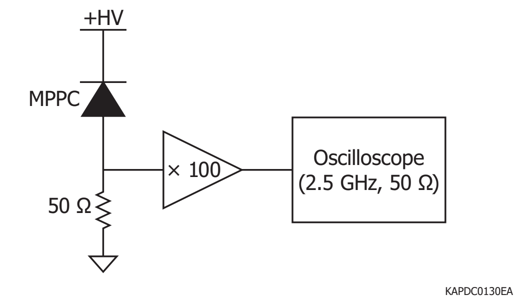
■ Measurement circuit



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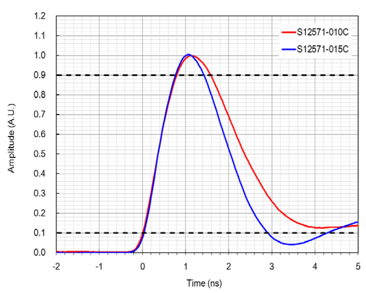
Parameter	S15639-1325PS	Unit
Gain	1.7 × 10^6	-
Pulse rise time	0.8	ns
Pulse fall time	14	ns
Microcell recovery time	46	ns

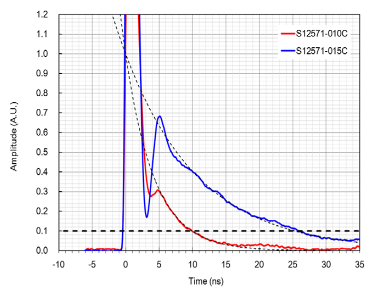
Definition of rise time, fall time, and recovery time

MPPC output pulse consists of two components: fast pulse and slow pulse. Fast pulse flows through the parasitic capacitance between the micro cell and the surrounding metal trace. Slow pulse flows through the quenching resistance, recovery time of which depends on the time constant of the junction capacitance and the quenching resistance.

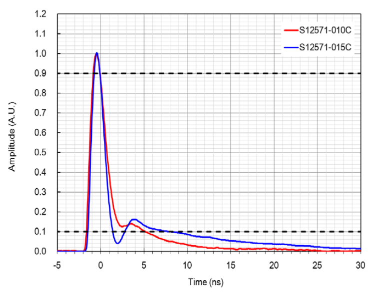
Rise time:
10% to 90% of the peak amplitude



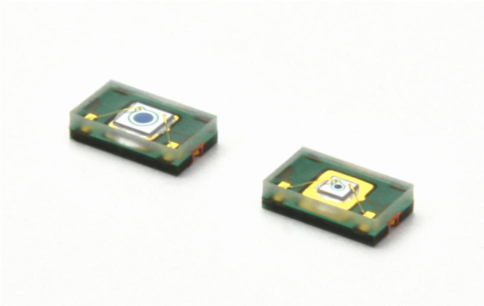
Recovery time:
90% to 10% of the slow pulse



Fall time:
90% to 10% of the peak amplitude

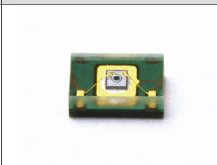
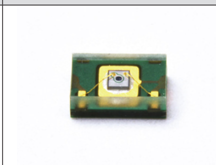
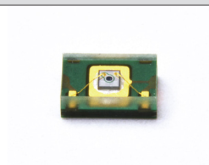


Si APD



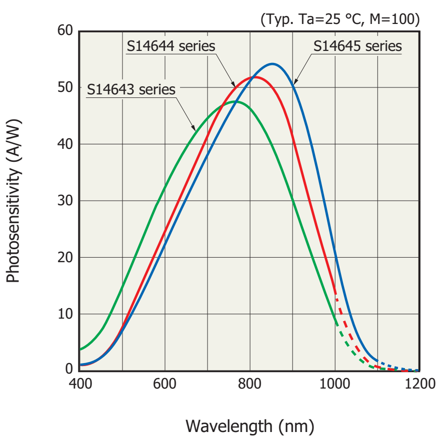
These Si APDs are designed to provide a peak sensitivity wavelength suitable for optical rangefinders. These deliver faster response and lower bias operation. The small, thin leadless package allows reducing the mounting area on a printed circuit board.

Specifications (Typ. Ta=25 ℃)

Parameter	Symbol	S14643-02	S14644-02/-05	S14645-02/-05	Unit
Photo	-				-
Type	-	Low bias voltage	Standard		-
Photosensitive area	-	ϕ0.2	ϕ0.2 / ϕ0.5		mm
Spectral response range	λ	400 to 1000		400 to 1100	nm
Peak sensitivity wavelength	λp	760	800	840	nm
Cutoff frequency	Fc	2.0	1.2 / 1.0	0.6 / 0.6	GHz
Terminal capacitance	Ct	0.7	0.6 / 1.6	0.5 / 1.0	pF
Breakdown voltage max.	V_{BR}	120	180	195	V
Temp. coefficient of V_{BR}	ΔTV_{BR}	0.42	0.63	1.1	V/℃

Spectral response

S14643/S14644/S14645 series



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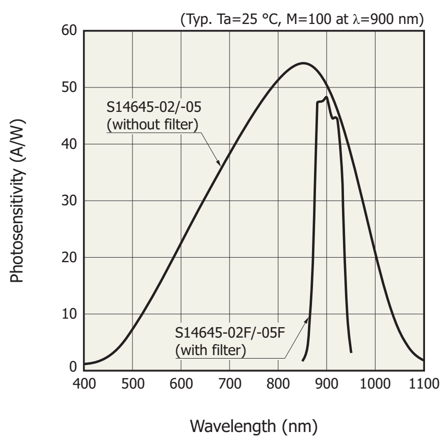
With 900 nm band-pass filter (S14645-02/-05)



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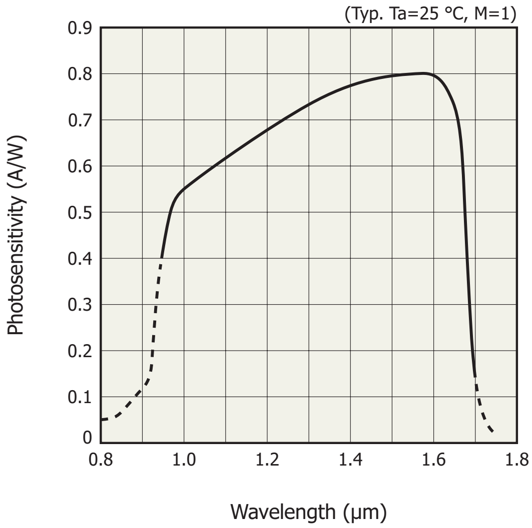
InGaAs APD

The G14858-0020AB is an InGaAs APD designed for distance measurement application using 1550 nm wavelength.
The photosensitive area is ϕ0.2mm and it can provide high-speed response (typical cutoff frequency: 0.9 GHz at M=10).
Compared to the conventional product, dark current characteristics was drastically improved.
The G14858-0020AB is lower cost version for LIDAR application.

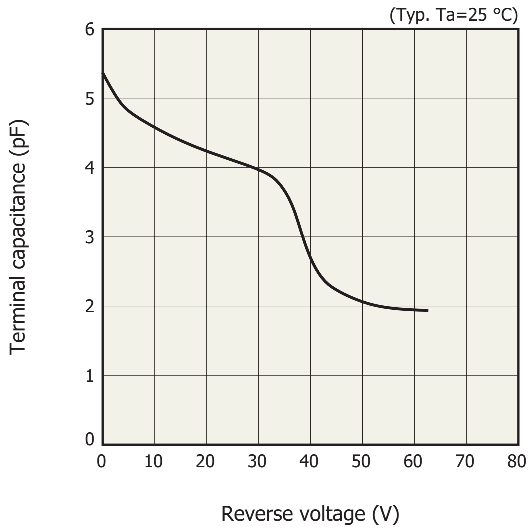
Specifications (Typ. Ta=25 ℃)

Parameter	Symbol	Condition	G14858-0020AB	Unit
Reverse current max.	I_R max		2	mA
Forward current max.	I_F max		10	mA
Operating temperature	Topr		-40 to +85	℃
Storage temperature	Tstg		-55 to +125	℃
Spectral response range	λ		0.95 to 1.7	µm
Peak sensitivity wavelength	λp		1.55	µm
Active area	-		ϕ0.2	mm
Photosensitivity	S	λ=1.55 µm, M=1	0.8	A/W
Breakdown voltage	V_{BR}	I_D=100 µA	65	V
Dark current	I_D	V_R=V_{BR} × 0.95	20	nA
Temperature coefficient of breakdown voltage	-	-40 to +85 ℃	0.1	V/℃
Gain	M	λ=1.55 µm, -30 dBm	30	-
Terminal capacitance	Ct	V_R=V_{BR} × 0.95, f=1 MHz	2.0	pF
Cutoff frequency	fc	M=10, R_L=50Ω	0.9	GHz

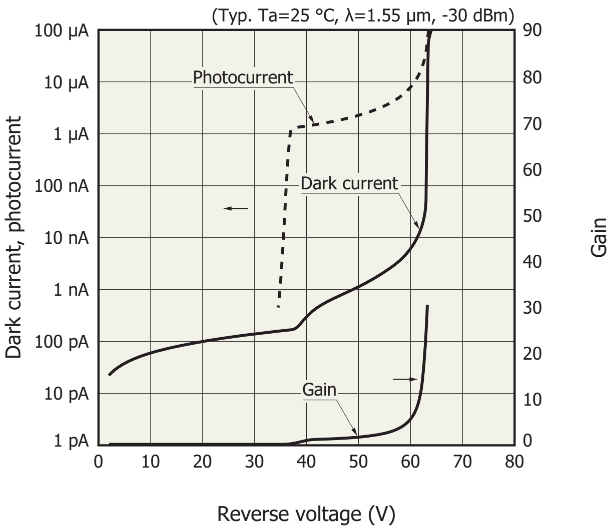
Spectral response



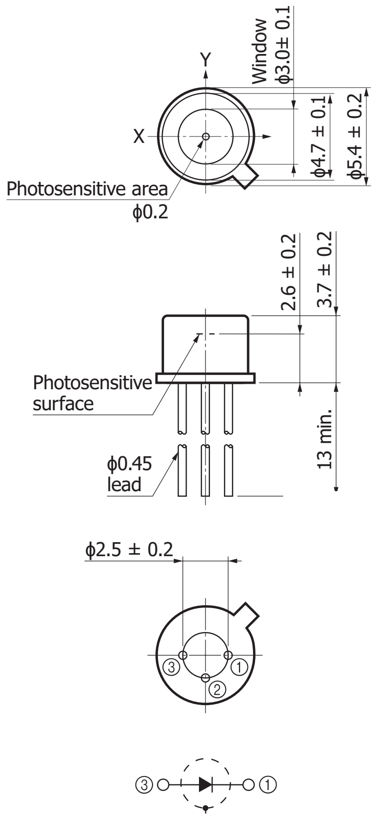
Terminal capacitance vs. reverse voltage



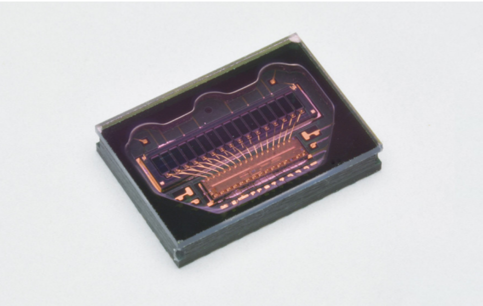
Dark current, photocurrent, gain vs. reverse voltage



Dimensional outline (unit: mm)



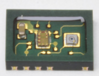
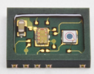
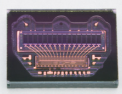
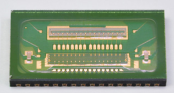
Photosensor with front-end IC



The photosensor with front-end IC is a product packaged with Si APD, which is a typical optical sensor used for TOF, as well as a readout circuit (TIA: trans-impedance amplifier).

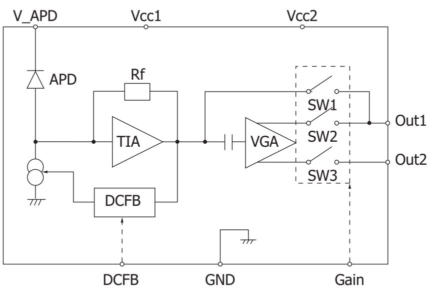
FEATURES
- Reduced mounting area compared to discrete semiconductors
- Reduced parasitic component (inductance and stray capacitance)
- Improved performance such as noise and frequency characteristics
- Customized for LiDAR applications with in-house design (APD, front-end IC):
  Built-in background light elimination (DCFB) circuit inside the IC

Specifications (Typ. Ta=25 ℃)

Parameter	S15597-01CT	S15658-01CT	S13645-01CR	S14137-01CR	Unit
Photo					-
Built-in APD	1-element (ϕ0.2 mm)	1-element (ϕ0.5 mm)	16-element (1.0 × 0.4 mm/ element)	16-element (0.15 × 0.43 mm/ element)	-
Number of outputs	1	1	1 (serial output)	16 (parallel output)	-
Output type	Differential (high gain)	Differential (high gain)	Differential (high gain)	Single (without high gain)	-
Photosensitivity (λ=905 nm)	3200 (high gain, M=100)	3200 (high gain, M=100)	900 (high gain, M=50)	36 (M=50)	kV/W
High cutoff frequency	160 (high gain)	150 (high gain)	160 (high gain)	180	MHz
Operating temperature	-40 to +105	-40 to +105	-40 to +105	-40 to +105	℃

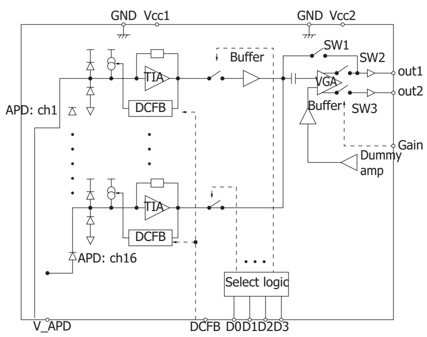
Block diagrams

S15597-01CT, S15658-01CT



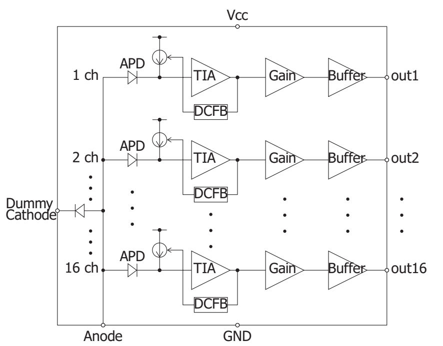
KPICC0367EA

S13645-01CR



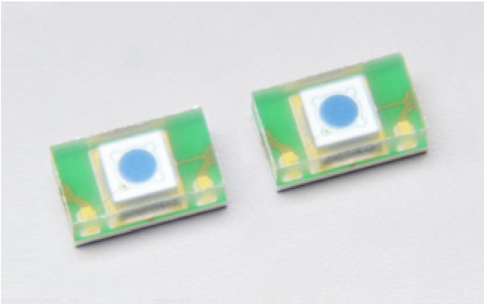
KPICC0368EA

S14137-01CR



KPICC0369EA

Si PIN photodiode

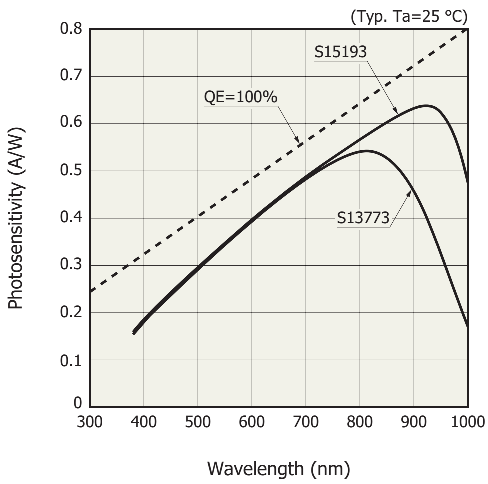


The S13773 and S15193 are Si PIN photodiodes with sensitivities in the visible to near infrared range and are compatible with lead-free solder reflow. The S13773 features high-speed response while the S15193 features improved near infrared sensitivity.
They are suitable for distance measurement laser monitoring.

Specifications (Typ. Ta=25 ℃)

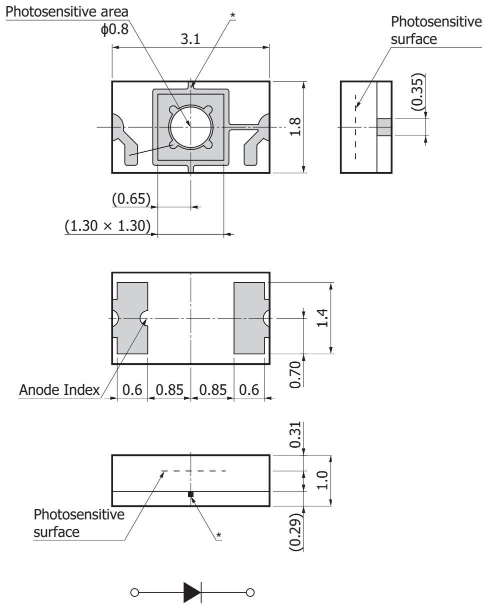
Parameter	Symbol	S13773	S15193	Unit
Operating temperature	Topr	-40 to +100		℃
Strage temperature	Tstg	-40 to +100		℃
Photosensitive area	-	ϕ 0.8		mm
Spectral response range	λ	380 to 1000		nm
Peak sensitivity wavelength	λ p	800	920	nm
Cutoff frequency	Fc	500	100	MHz
Terminal capacitance	Ct	3	2	pF
Reflow soldering conditions	-	Peak temperature 260 ℃, 3 times		-

Spectral response



KPINB0406EC

Dimensional outline (unit: mm)



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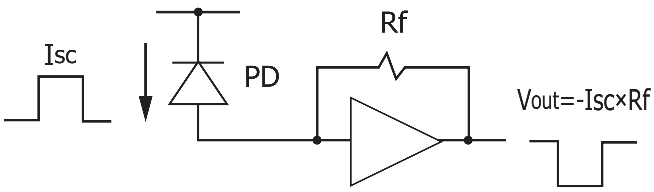
Information

Transimpedance amplifier (TIA)

Transimpedance amplifiers (TIAs) are readout circuits that quickly convert current Isc (which occurs in the photodiode) into voltage (Vout = -Isc × Rf). The output represents the instantaneous value of the incident light, within the trackable range. They are often used in the receiver front end and incident light timing detection in optical communication applications. Figure 1 shows the basic circuit structure.

[Figure 1] TIA circuit diagram



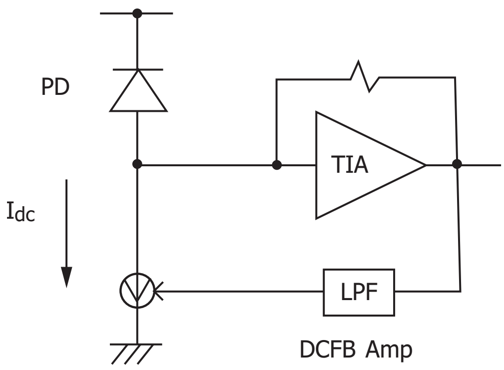
Hamamatsu Photonics provides high-speed low-noise TIAs and proposes photosensor with front-end IC which integrate such as Si PIN photodiode / APD / InGaAs photodiode and TIA in one package. Packaging the detector and TIA into a single device reduces parasitic capacitance and inductance and improves noise and frequency characteristics.

Background light countermeasures

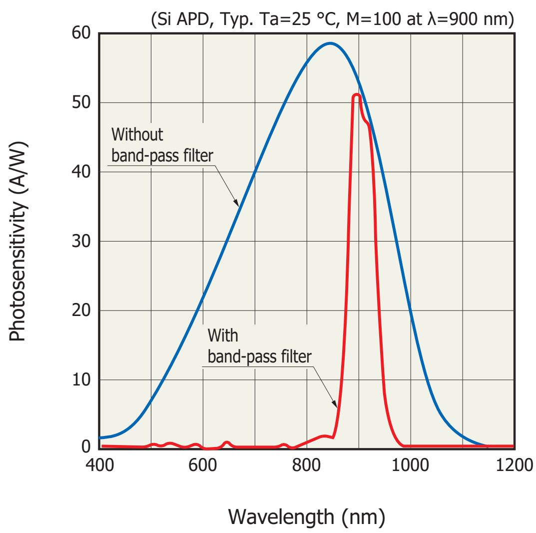
In the case of a PIN photodiode or APD, a DC feedback circuit can be used to eliminate background light. Figure 2 shows a circuit example using a DC feedback circuit.

In addition, a band-pass filter can be used to cut light with wavelengths other than that used for the light source. Figure 3 shows a sensitivity measurement example of a detector with a band-pass filter.

[Figure 2] DC feedback circuit



[Figure 3] Band-pass filter implementation example



Light source (Pulsed laser diode)

These LDs feature high peak power under pulsed operation. Various types are available with different peak output power and emission widths. These LDs can be used for distance measurements such as LiDAR, hazard monitoring in security applications, etc.

(Please refer to our website: https://www.hamamatsu.com/all/en/product/lasers/semiconductor-lasers/plds/index.html)

Type no.	Peak output power (W)	Peak emission wavelength (nm)	Emitting area size (μm)	Duty ratio (%)	Photo
L11348-307-05	21	870	70 × 10	0.1	
L11649-120-04	20	870	200 × 1	0.1	
L11854-307-05	21	905	70 × 10	0.1	
L11854-323-51	75	905	230 × 10	0.1	
L11854-336-05	100	905	360 × 10	0.1	
L15326-01 NEW	70 (per channel)	905	230 × 10 (per channel)	0.05	

MPPC is a registrated trademark of Hamamatsu Photonics K.K.
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