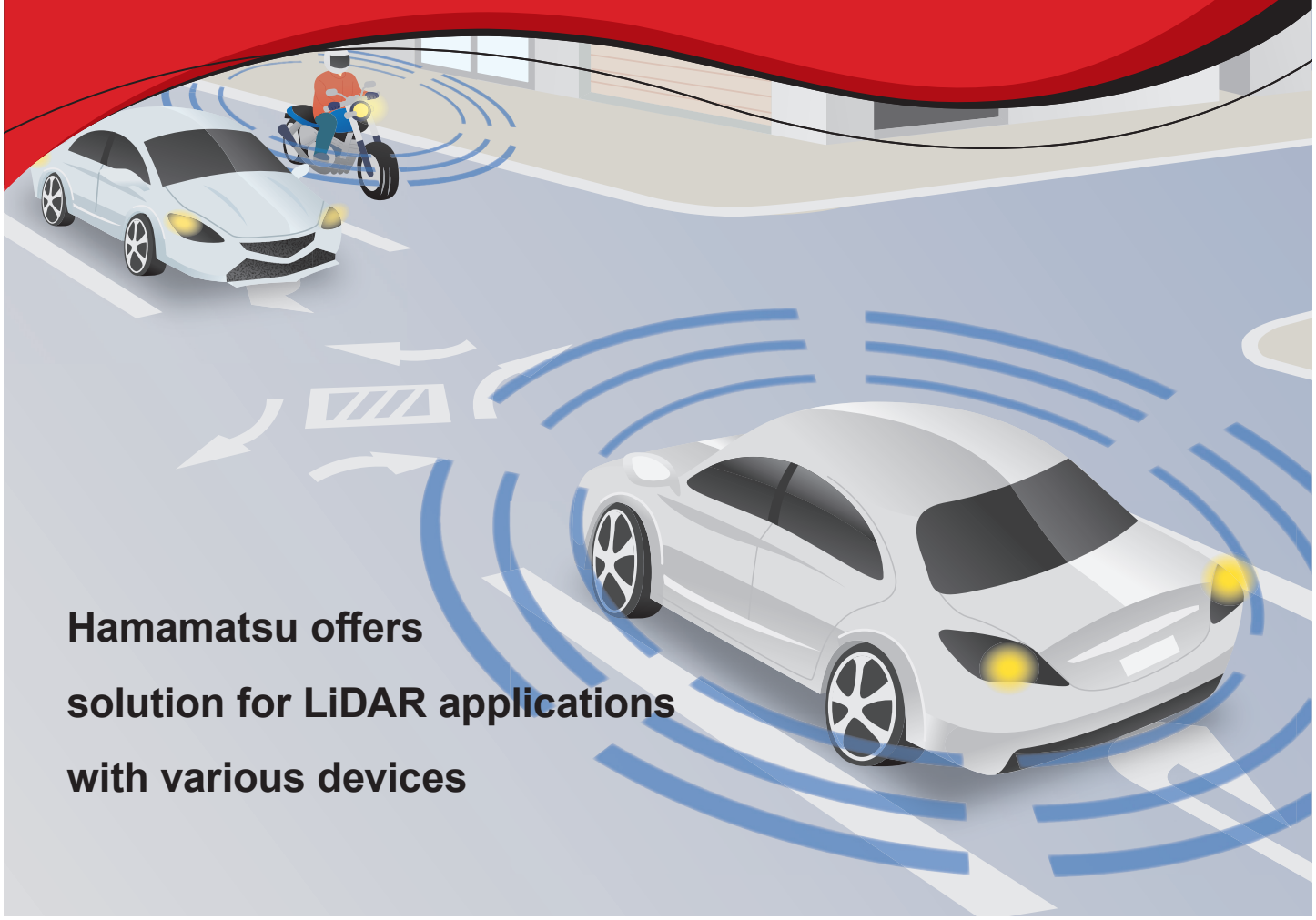
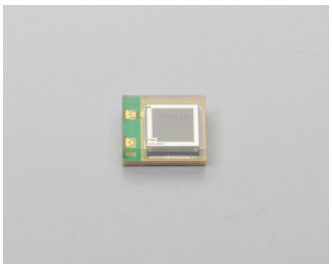
Jun. 2019

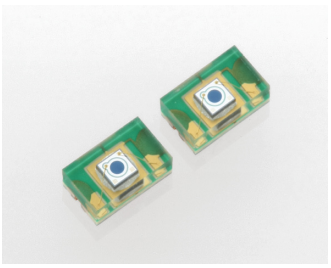
Photodetectors for LiDAR



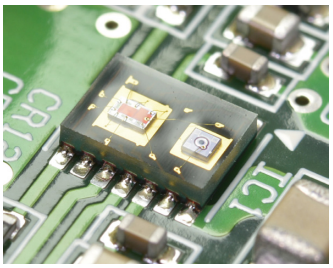
Hamamatsu offers
solution for LiDAR applications
with various devices



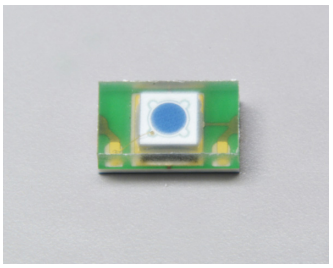
MPPC®
(multi-pixel photo counter)



APD



Photosensor with
front-end IC



PIN photodiode

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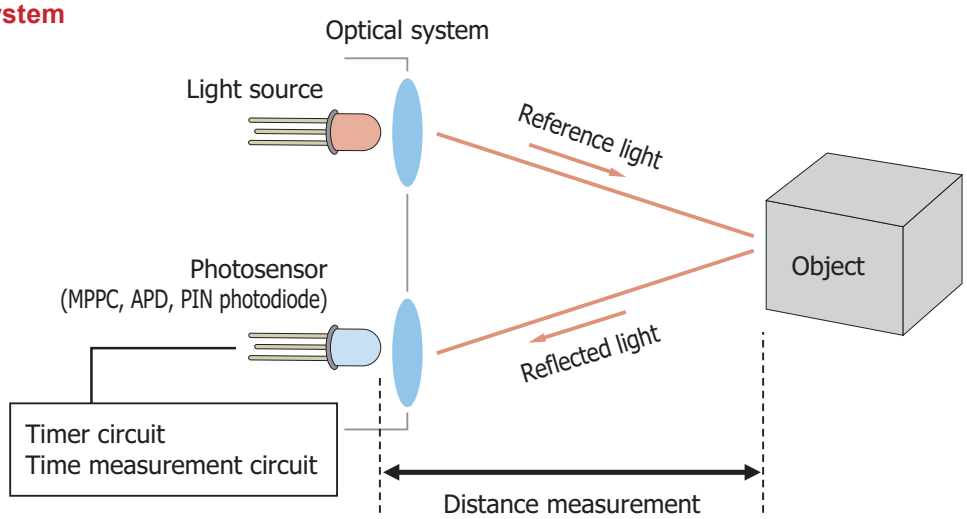
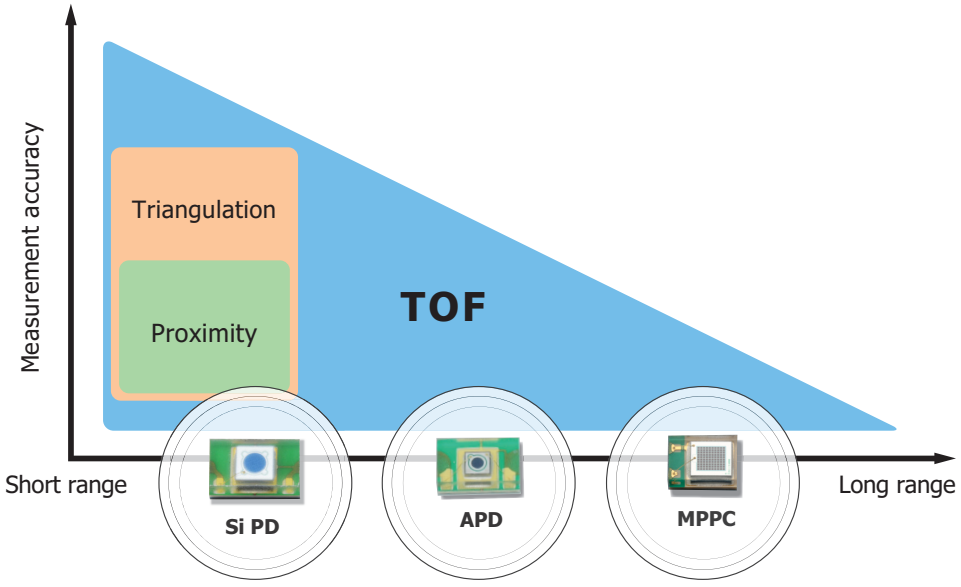
What is Time of Flight (TOF)?

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 a 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



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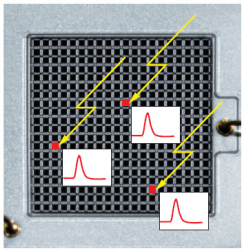
Detector demands for LiDAR applications

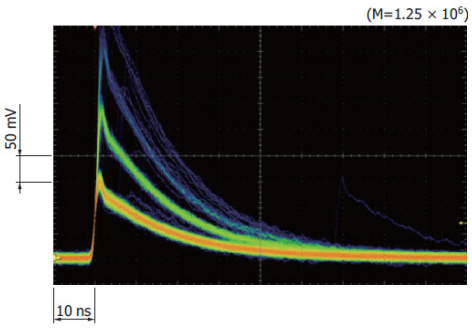
- High sensitivity, Low noise
- Usable under strong ambient light condition
  - Especially in automotive application
- Usable under wide temperature range
- Mass productivity and low cost
- High speed response
- Wide dynamic range
  - From a distance black target (very weak reflected light) to nearby 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 obtained multiplication factor of 10^5 to 10^6.
As for the distance meter, treat of background light becomes more important. Most simply as for the distance meter, the minimum reception level is the background light intensity. Optical bandpass filter will be more important. The readout circuit, good S/N is obtained in the high-impedance type circuit. It is possible to reduce the readout circuit, you can achieve a low-cost rangefinder system in total. In addition, as an array type, that the received circuit is simple it is advantageous.





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, in the rangefinder, often used is several tens of times of the multiplication factor to 10 times. 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 optical bandpass filters. The readout circuit, as in the case of PIN photodiode, transimpedance amplifier will be used.

Suitable for:

- Long range
- Direct TOF
- High ambient light with bandpass filter

PIN photodiode

As for rangefinder, it is the most simple light-receiving element. Its sensitivity is stable, it is uniform. Wide dynamic range. It can also be used under strong background light. The read circuit, and the transimpedance amplifier is widely used. 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

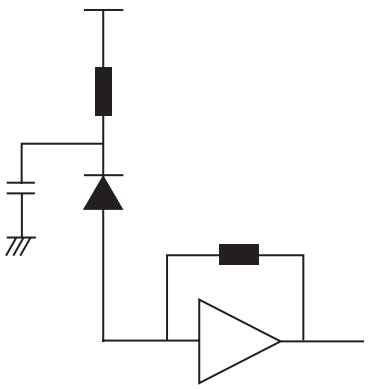
Comparison chart

Parameter	MPPC	APD	PIN photodiode
Range	Long	Long	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 sensitivity	Middle	High	Low
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 circuit

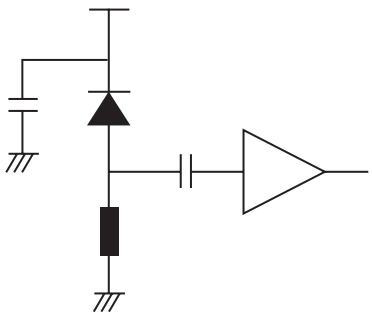
Transimpedance amplifier

*Suitable for MPPC, APD and PIN photodiode



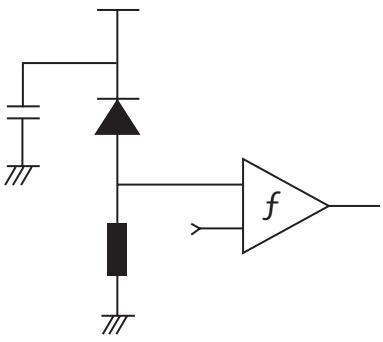
Register with high frequency amplifier

*Suitable for MPPC

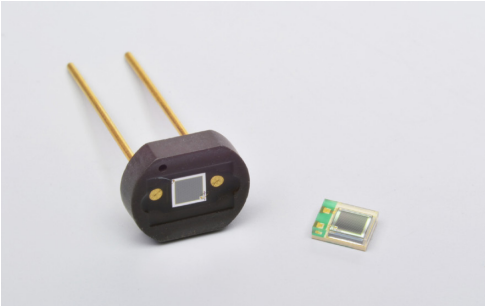


Register with high comparator

*Suitable for MPPC



MPPC®



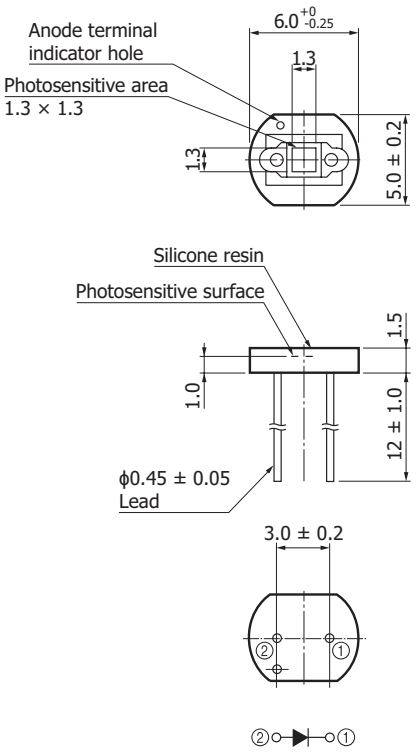
The S13720-1325CS/PS are MPPC for LiDAR applications. These feature high sensitivity to near-infrared wavelengths.
The photon detection efficiency (PDE) at near-infrared wavelengths, often used in LiDAR, has been improved over our previous products.
Ceramic package type and surface mount type with a photosensitive area of 1.3 × 1.3 mm and pixel pitch of 25 μm are available.
We also provide an evaluation module for the S13720-1325 series.

Specifications (Typ. Ta=25 ℃)

Parameter		Symbol	S13720-1325CS	S13720-1325PS	Unit
Photo		-			-
Package		-	Ceramic	Surface mount type	-
Operating temperature		-	-40 to +85		℃
Storage temperature		-	-40 to +105		℃
Soldering condition		-	350 ℃ max. once, within 3 second	240 ℃ max. 3 times	-
Effective photosensitive area		-	1.3 × 1.3		mm
Pixel pitch		-	25		μm
Number of pixels / channels		-	2668		pixels
Geometrical fill factor		-	47		%
Window material		-	Silicone resin		-
Window refractive index		-	1.41	1.57	-
Spectral response range		λ	350 to 1000		nm
Peak sensitivity wavelength		λp	660		nm
Photon detection efficiency (λ=λp)		PDE	22		%
Photon detection efficiency (λ=905 nm)		PDE	7		%
Breakdown voltage		V_{BR}	57 ± 5		V
Recommended operating voltage		V_{op}	V_{BR} + 7		V
Dark count	typ.	-	500		kcps
	max.	-	1500		
Crosstalk probability		-	6		%
Terminal capacitance		Ct	65		pF
Gain		M	1.1×10^6		-
Temperature coefficient of recommended operating voltage		ΔTVop	54		mV/℃

Dimensional outlines (unit: mm)

S13720-1325CS



Lead material: Fe-Ni-Co alloy
Lead processing: Au plating
Tolerance unless otherwise noted: ±0.2
Chip position accuracy:
X, Y≤±0.25 with respect to package center
The coating resin may extend a maximum of
0.1 mm above the upper surface of the package.

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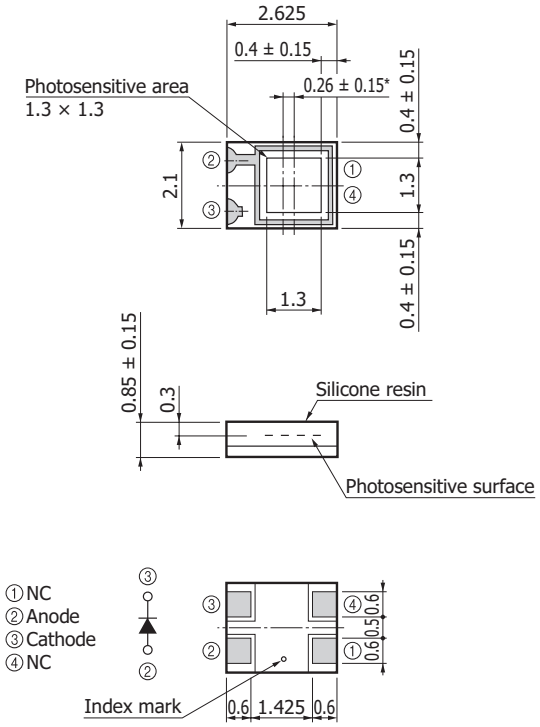
S13720-1325PS



Tolerance unless otherwise noted: ±0.1
* Distance from chip center to package center

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MPPC module C14193-1325SA

For evaluation

The C14193-1325SA is an optical measurement module capable of detecting low level light. It consists of an MPPC, a high-speed amplifier circuit, a high-voltage circuit, and a temperature compensation circuit. Utilizing a small pixel pitch MPPC allows high-speed measurement over a wide dynamic range, making the C14193-1325SA suitable for high-speed signal measurement such as distance measurement. The C14193-1325SA operate just by connecting it to an external single power supply (+5 V).

Type No.	Built-in MPPC	Effective photosensitive area	Pixel pitch
C14193-1325SA	S13720-1325CS	1.3 × 1.3 mm	25 µm

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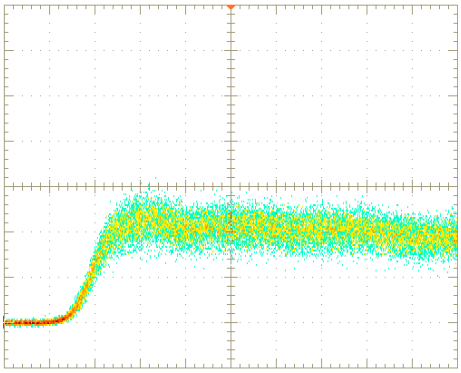
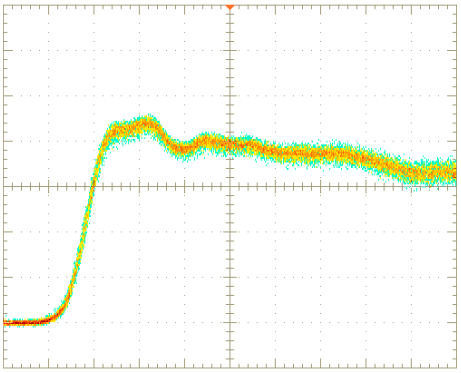
Features of MPPC

Feature 1 Waveform is very stable even under saturated conditions.

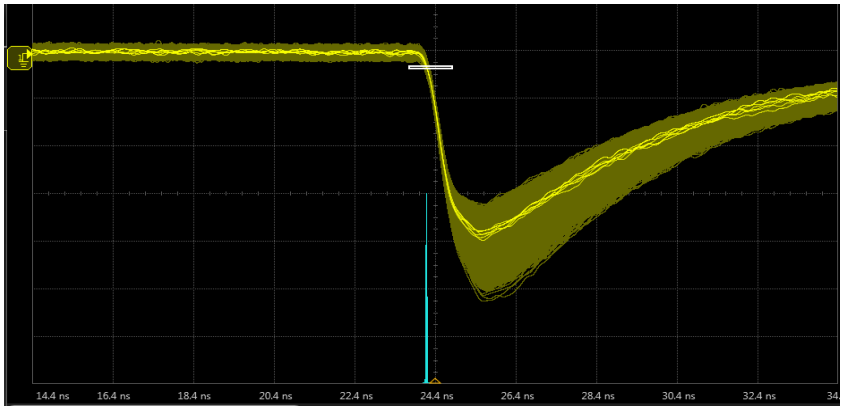
Weak light input	Saturated light input





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

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



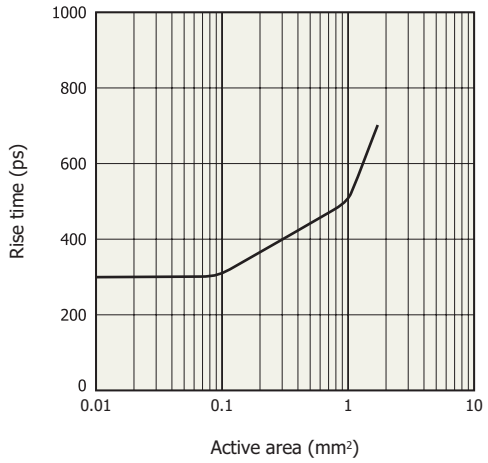
MPPC S12571-015P
Photosensitive area: 1 × 1 mm
Pixel size: 15 μm

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

Feature 4 **Bigger output is obtained with small active area MPPC**

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

Rise time vs. active area



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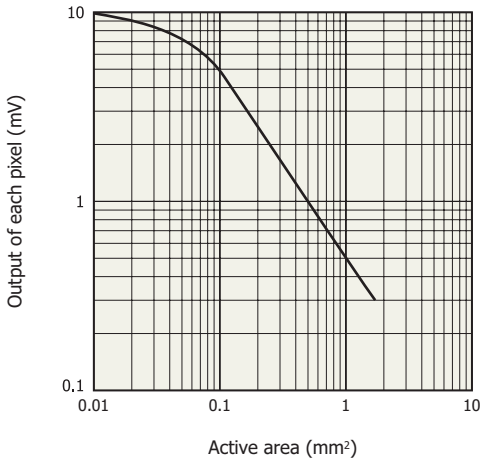
Output of each pixel vs. active area



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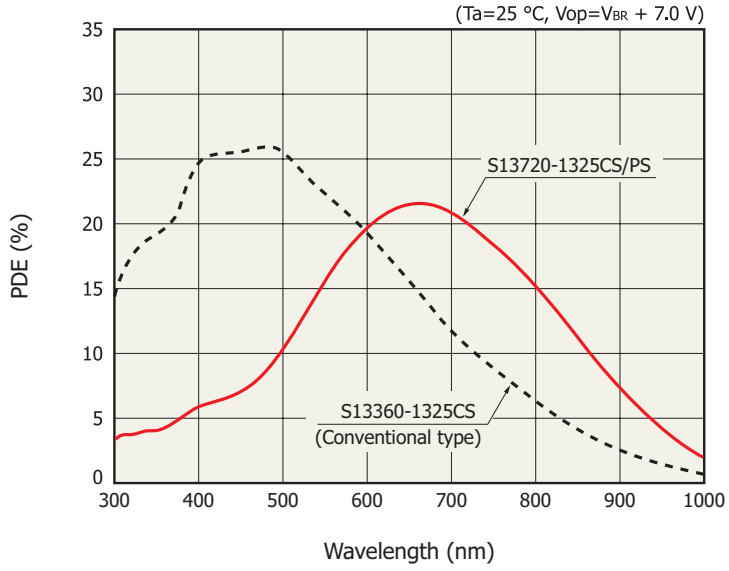
Feature 5 **High sensitivity in the 905 nm band (compared to previous products)**

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

PDE vs. wavelength



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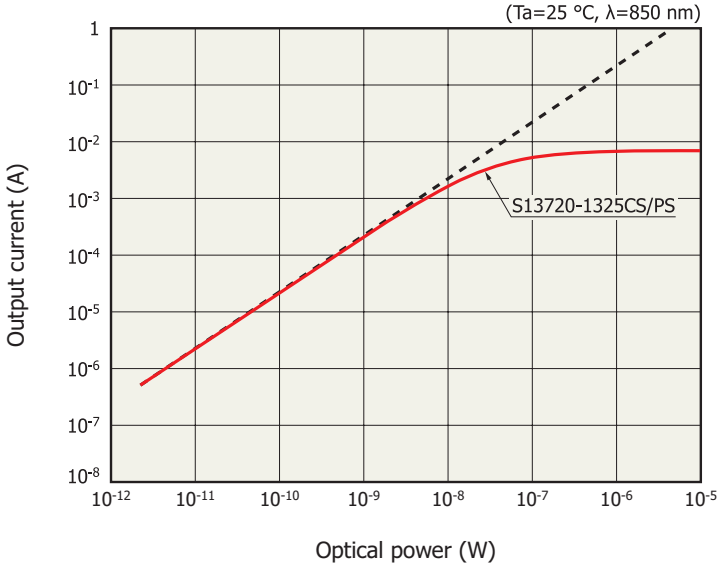
Feature 6 Wide dynamic range and background light suppression

Linearity



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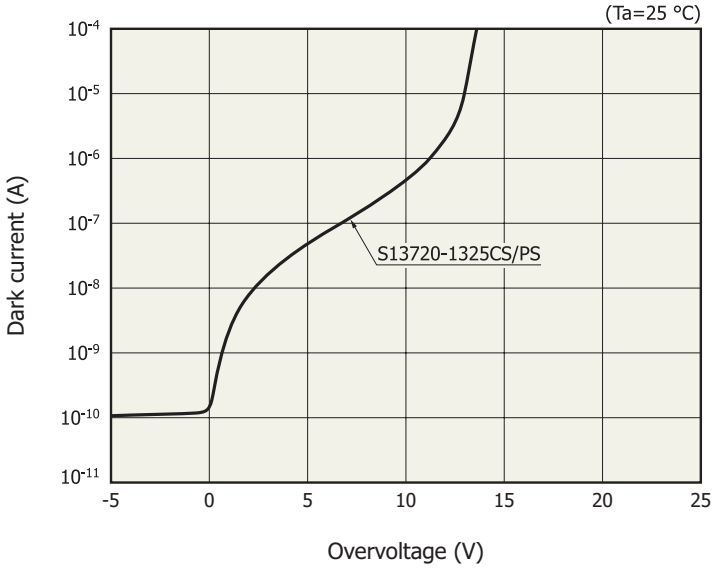
- Using narrow bandpass filter
- Reduce field of view
  - Tele lens
  - Small area detector

Feature 7 Low operating voltage and wide voltage range

Dark current vs. overvoltage



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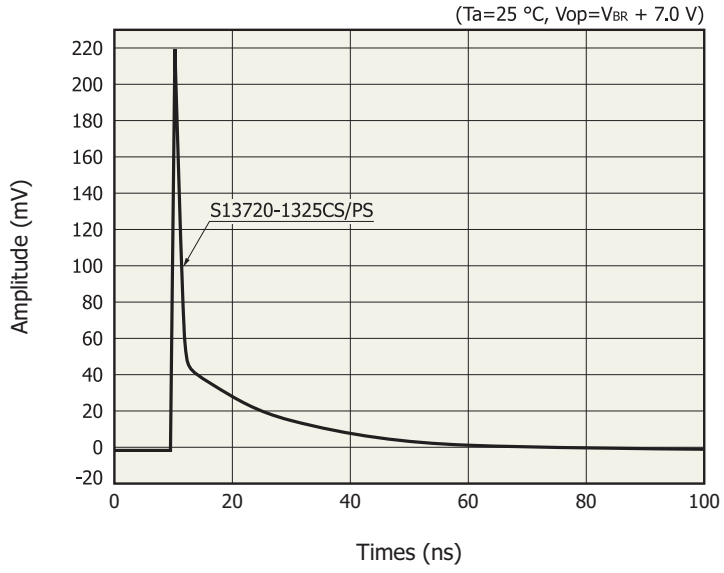
Feature 8 Fast rise time and recovery time

- 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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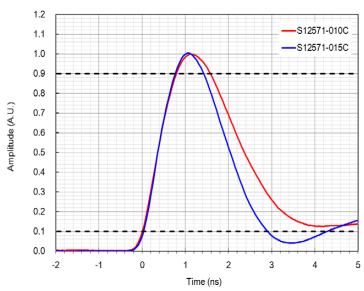
Parameter	Symbol	S13720-1325CS	S13720-1325PS	Unit
Terminal capacitance	Ct	65		pF
Junction capacitance	Cj	28		fF
Gain	-	1.1×10^6		-
Pulse rise time	-	0.7		ns
Pulse fall time	-	14		ns
Microcell recovery time	-	40		ns

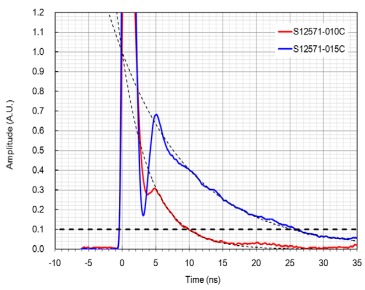
Definition of rise time, fall time and recoverry time

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.

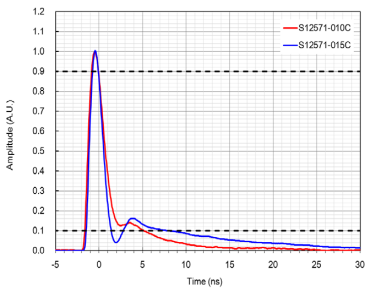
Rise time:
10% to 90% of the peak amplitude



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



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



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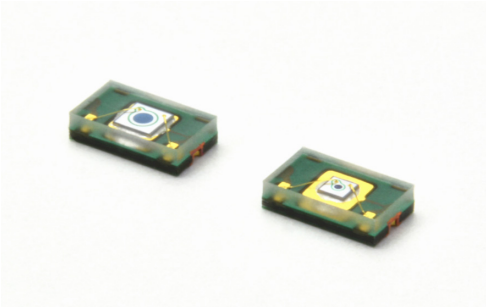
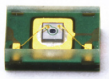
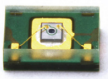
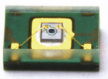
Si APD



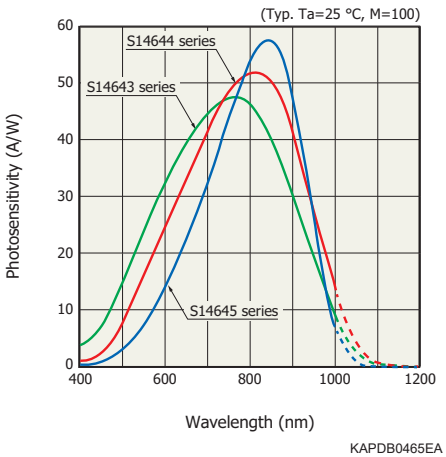
These Si APDs are designed to provide a peak sensitivity wavelength suitable for optical rangefinders. These deliver faster response and lower bias operation. The small, thin leadless package allows reducing the mounting area on a printed circuit board.

Specifications (Typ. Ta=25 ℃)

Parameter	Symbol	NEW S14643-02	NEW S14644-02/-05	NEW 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}	ΔT_{VBR}	0.42	0.63	1.1	V/℃

Spectral responses

S14643/S14644/S14645 series



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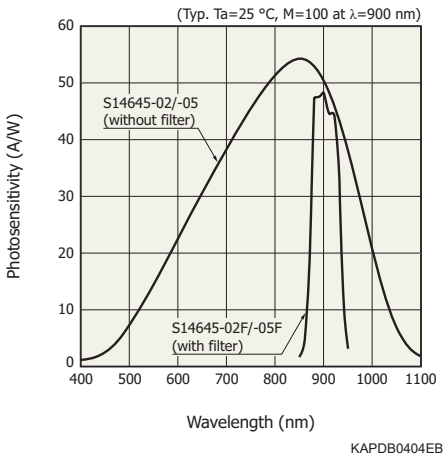
With 900 nm band-pass filter (S14645-02/-05)



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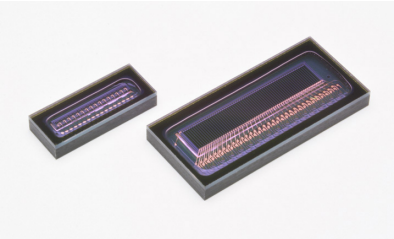
NEXT PLAN

Si APD array



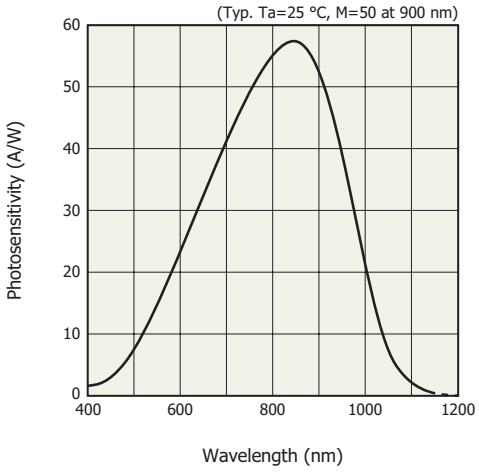
The next Si APD will realize array detector designed for distance measurement application, and they have peak sensitivity at near infrared wavelength. The 16 ch linear array type and the 64 ch linear array type are planning to be released.

Specifications (Typ. Ta=25 ℃, per 1 element)

Parameter	16 ch type	64 ch type	Unit
Operating temperature range	-40 to +105		℃
Storage temperature range	-40 to +125		℃
Element size (W × H)	0.43 × 0.15	0.16 × 2.5	mm
Element gap	0.07		mm
Spectral response range	500 to 1040		nm
Peak sensitivity wavelength	840		nm
Photosensitivity*1	27.5 (λ =850 nm) 25.0 (λ =900 nm)		A/W
Breakdown voltage*2	180		V
Cutoff frequency*3	400		MHz
Terminal capacitance*4	0.6	1.5	pF
Gain	50		-

*1: M=50 *2: I_D=100 μA *3: M=50, R_L=50 Ω, λ =850 nm, -3dB *4: M=50, f=1 MHz

Spectral response



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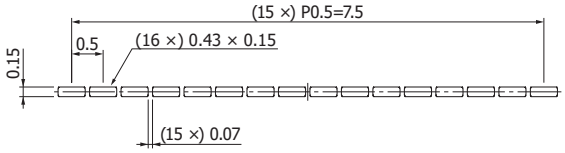
Enlarged drawing of photosensitive area (unit: mm)

<16 ch type>



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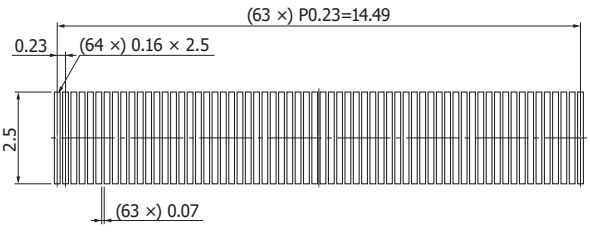

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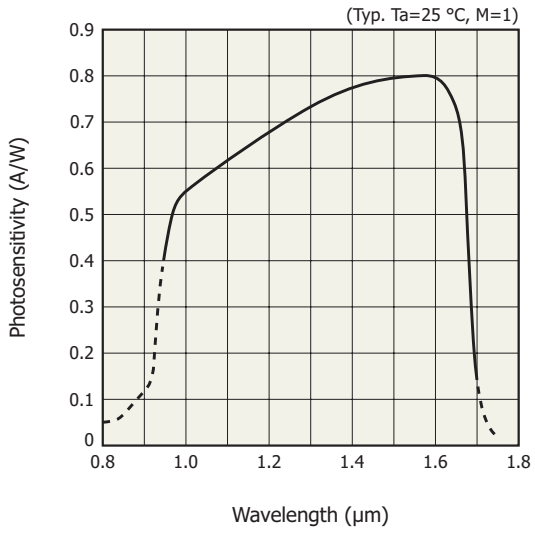
InGaAs APD

G14858-0020AB is an InGaAs APD designed for distance measurement application using 1550 nm wavelength.
The active 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.
* G14858-0020AB is lower cost version for LIDAR application.

Specifications (Typ. Ta=25 ℃)

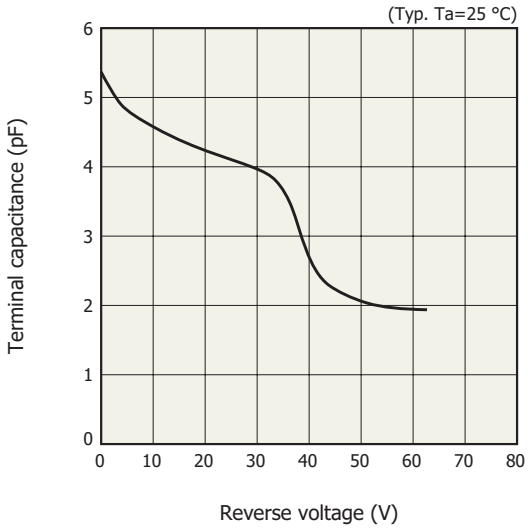
Parameter	Symbol	Condition	NEW G14858-0020AB	Unit
Reverse current max.	I_R max		2	mA
Forward current max.	I_F max		10	mA
Operating temperature range	-		-40 to +85	℃
Strage temperature range	-		-55 to +125	℃
Spectral response range	λ		0.95 to 1.7	μm
Peak sensitivity wavelength	λp		1.55	μm
Active area	-		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
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



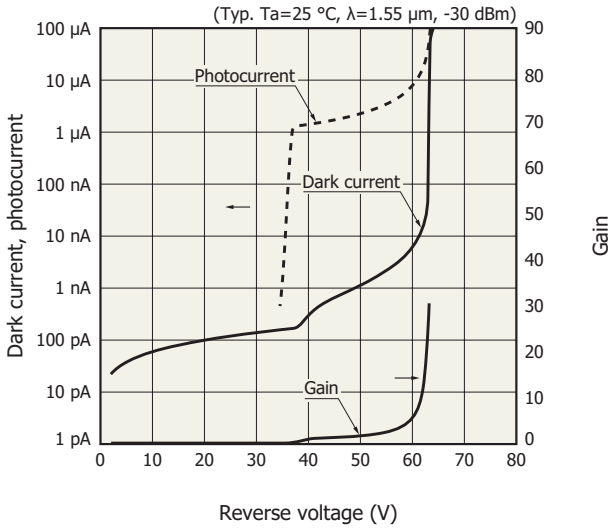
KAPDB0417EA

Terminal capacitance vs. reverse voltage



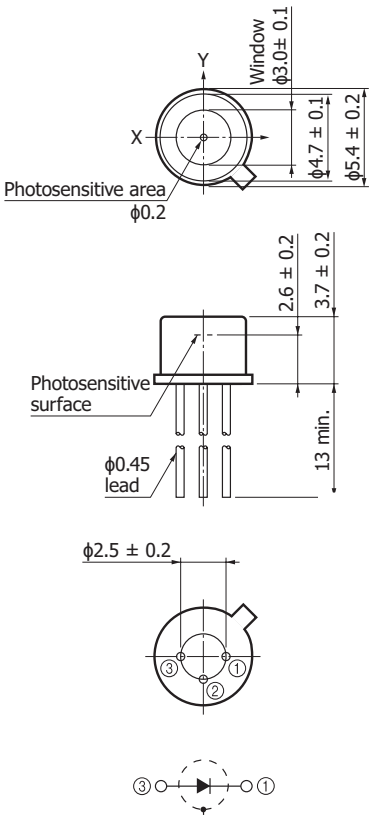
KAPDB0418EA

Dark current vs. reverse voltage
Gain vs. reverse voltage



KAPDB0423EA

Dimensional outline (unit: mm)



KAPDA0192EA

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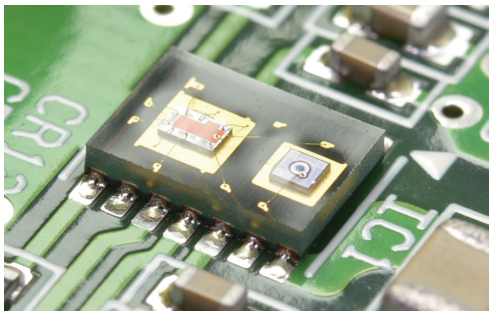
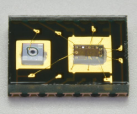
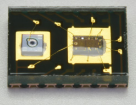
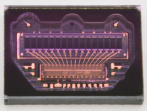
Photosensor with front-end IC



Photosensor with front-end IC is integration of photosensor - such as Si photodiode and InGaAs APD - and front-end IC that reads the signals from the photosensor. When compared with discrete circuits, photosensor with front-end IC has the following advantages.

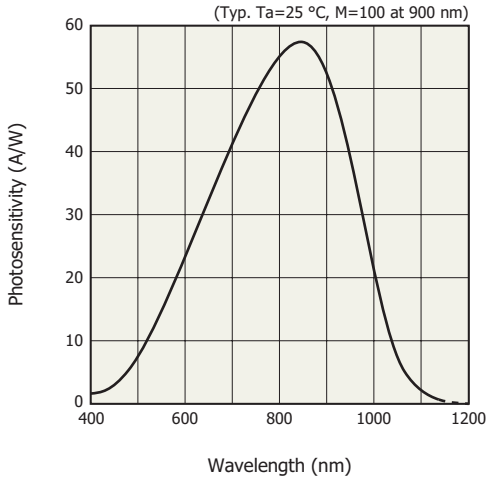
- Reduced external noise effects.
- Reduced parasitic elements (inductance and stray capacitance). Improved performance characteristics such as noise characteristics and frequency characteristics.
- Original opto-semiconductor process contributes the characteristics of photosensors that are retained outstanding performance and high efficiency.

Specifications (Typ. Ta=25 ℃)

Parameter	Symbol	S13282-01CR	S14847-01CR	S13645-01CR	Unit
Photo	-				-
Type	-	Si APD + TIA	Si APD + TIA	16ch Si APD + TIA array	-
Photosensitive area	-	ϕ 0.2	ϕ 0.5	7.9 × 1.0 (0.5 mm pitch)	mm
Peak sensitivity wavelength	λp	840	840	840	nm
Cutoff frequency	fc	180	170	180	MHz
Sensitivity	S	4 (M=100, λ=900 nm)	4 (M=100, λ=900 nm)	1 (M=50, λ=840 nm)	MV/W

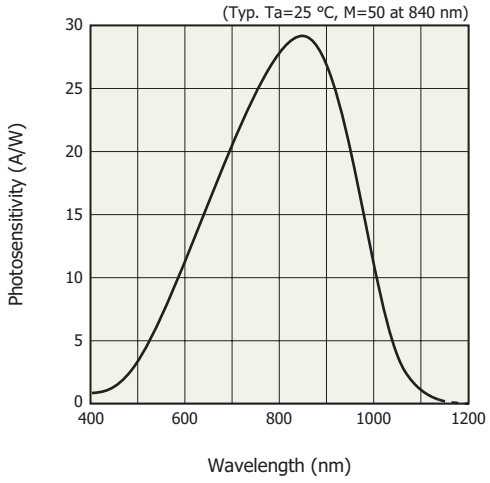
Spectral responses

S13282-01CR/S14847-01CR



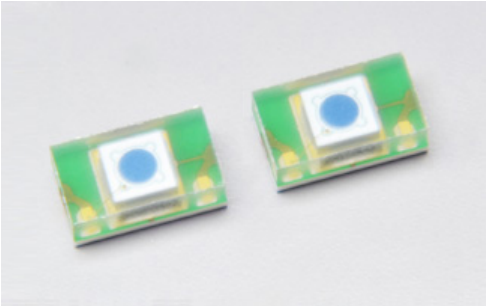
KAPDB0269EA

S13645-01CR



KAPDB0381EA

Si PIN photodiode

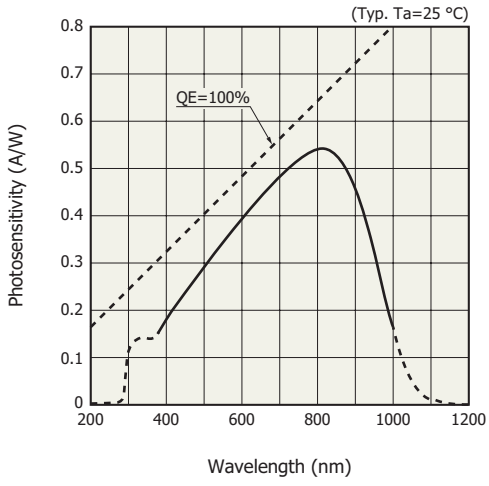


The S13773 is a Si PIN photodiode for visible to near infrared range and is compatible with lead-free solder reflow processes. The S13773 has feature of high speed response time that is suitable for range finder application.

Specifications (Typ. Ta=25 ℃)

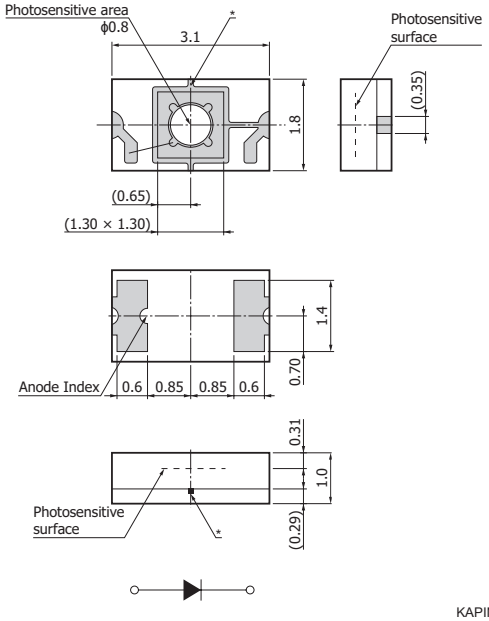
Parameter	Symbol	S13773	Unit
Operating temperature range	-	-40 to +100	℃
Strage temperature range	-	-40 to +100	℃
Photosensitive area	-	ϕ 0.8	mm
Spectral response range	λ	380 to 1000	nm
Peak sensitivity wavelength	λp	800	nm
Cutoff frequency	Fc	500	MHz
Terminal capacitance	Ct	3	pF
Reflow soldering conditions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

Spectral response



KPINB0406EA

Dimensional outline (unit: mm)



KAPINA0119EA

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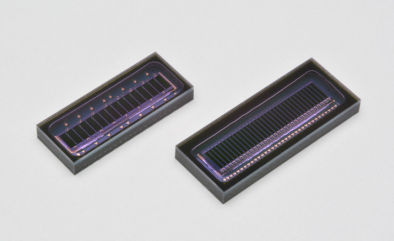
NEXT PLAN

Si PIN photodiode array



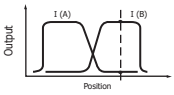
The next PIN photodiode will realize array detector for distance measurement application. Compared to existing photodiode array, higher response speed is achievable. They have peak sensitivity at near infrared wavelength. The 16 ch linear array type and the 32 ch linear array type are planning to be released.

Specifications (Typ. Ta=25 ℃, per 1 element)

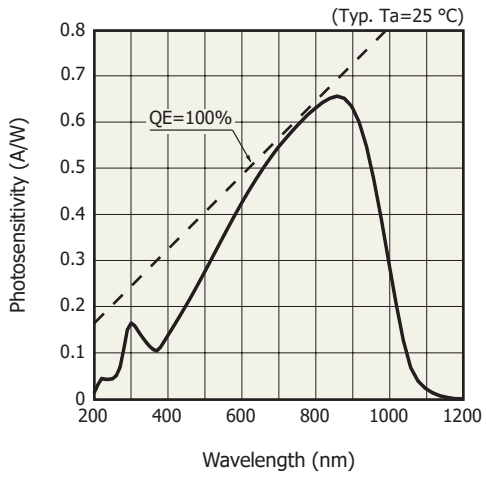
Parameter	16 ch type	32 ch type	Unit
Operating temperature range	-40 to +105		℃
Storage temperature range	-40 to +125		℃
Element size (W×H)	0.7 × 2.0	0.35 × 2.0	mm
Element gap	0.1		mm
Spectral response range	340 to 1100		nm
Peak sensitivity wavelength	860		nm
Photosensitivity (λ = λ p)	0.64		A/W
Dark current	0.05		nA
Cutoff frequency*1	120	80	MHz
Terminal capacitance*2	5	3	pF
Crosstalk*3	1		%

*1: V_R=10 V, R_L=50 Ω, λ =830 nm, -3dB

*2: V_R=10 V, f=1 MHz *3: Definition of crosstalk: CL=I (A)/I(B)×100

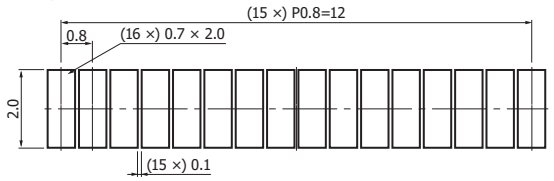


Spectral response



Enlarged drawing of photosensitive area (unit: mm)

<16 ch type>



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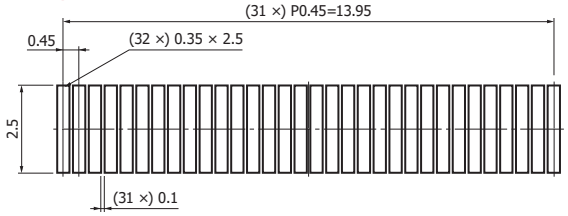
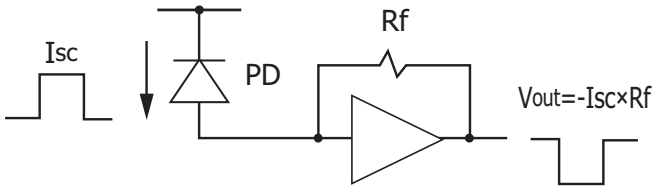


Information

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. It is 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



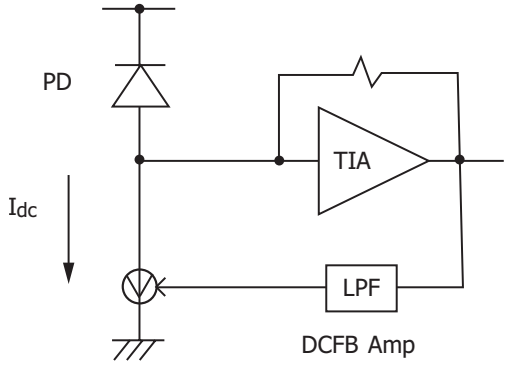
Hamamatsu Photonics provides high-speed low-noise TIAs and proposes photosensor with front-end IC which integrate such as Si PIN photodiode / APD / InGaAs photodiode and TIA in one package. Packaging these detectors and TIA into a single device reduces parasitic capacitance and inductance and improves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

Background light countermeasures

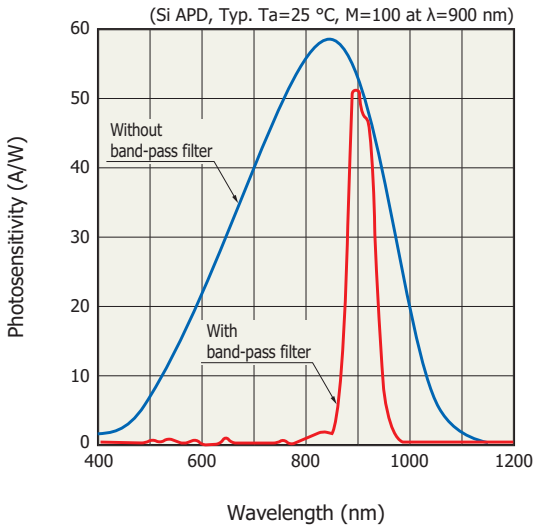
In the case of a PIN-PD or APD, a DC feedback circuit can be used to eliminate background light. Figure 2 shows a circuit example using a DC feedback circuit.

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



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Light source

Hamamatsu also provides light sources for distance measurement, LiDAR, etc.
(Please refer to our website:
http://www.hamamatsu.com/all/en/product/category/1001/1004/index.html)

Products	Peak output power (W)	Peak emission wavelength (nm)	Emitting area size (μm)	Duty ratio (%)
Pulsed laser diode L11649-120-04	20	870	200 × 1 μm	0.1
Pulsed laser diode L11348-307-05	21	870	70 × 10 μm	0.1
Pulsed laser diode L11854-307-05	21	905	70 × 10 μm	0.1
Pulsed laser diode L11854-323-51	75	905	230 × 10 μm	0.1
Pulsed laser diode L12169-336-51	100	870	360 × 10 μm	0.1
Pulsed laser diode L11854-336-05	100	905	360 × 10 μm	0.1

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