Glossary

A

Activation energy

This is the energy required for a substance to perform a reaction. In the Arrhenius equation for calculating the speed of a chemical reaction, activation energy is used as an indicator for expressing how difficult it is for a chemical reaction to occur. The Arrhenius equation is used to calculate the LED service life and the like. The activation energy of LED degradation is obtained from the failure rate under several temperature conditions.

Afterpulse

Afterpulses are pseudo signal pulses following the true signal output pulse. In an MPPC, this indicates a phenomenon that produces pulses other than signals when the generated carriers are trapped by crystal defects and then released at a certain time delay. Afterpulses can cause detection errors the same as from crosstalk and dark pulses. The lower the temperature, the higher the probability that carriers may be trapped by crystal defects, so afterpulses will increase.

Amorphous

Noncrystalline state having no definite form. For example, when a liquid or gaseous semiconductor is cooled and solidified so rapidly that no crystals are formed, it becomes amorphous. In this state, the crystal structure has a short-distance order but does not have a long-distance order, and a tail level appears at the band gap edge, making the optical characteristics different from those of monocrystalline or polycrystalline materials.

Anisotropic etching

An etching process in which the etching speed in a particular direction is different from that in other directions. For example, when a (100) silicon substrate is wet-etched using alkaline solution, V-grooves are formed due to the fact that the etching speed on the (100) plane is faster than that on the (111) plane. Etching in which the etching speed is the same in all directions is called isotropic etching.

Anodic bonding

When the flat surface of glass containing alkali metal is attached to the flat surface of silicon and heated while a voltage is being applied, an electrostatic attractive force is generated at the interface between the glass and silicon. Anodic bonding is the bonding technique that makes use of this phenomenon. During anodic bonding, the silicon side is used as the anode.

Arrhenius equation

The equation (see below) describing the temperature dependence of chemical/physical reaction speeds, proposed by S. A. Arrhenius (Sweden) in 1889. This equation is used to calculate the expected life of a component when a major cause of degradation of the component is probably temperature.

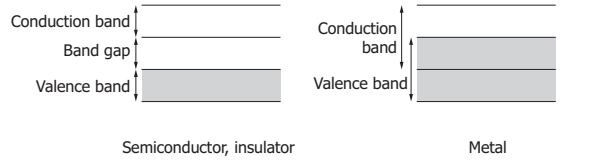
$$K = A \times \exp(-Ea/k\,T)$$

K : reaction speed
A : constant
Ea: activation energy [eV]
k : Boltzmann's constant [eV/K]
T : absolute temperature [K]

B

Band gap energy

In a semiconductor, insulator, or metal, electrons surrounding the nucleus are present in energy levels with a certain width. In semiconductors or insulators, among the energy bands where electrons exist, the highest energy band filled with electrons at absolute zero degrees is called the valence band, and the energy band with no electrons is called the conduction band. The energy range in the band gap (forbidden band) between the valence band and the conduction band is called the band gap energy. In metals, there is no band gap because the valence band and conduction band overlap each other.



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Bias T

A circuit used to apply a DC bias to a device. This circuit is capable of applying a DC bias while maintaining an impedance match and is therefore needed when using a high-speed device.

Bit error rate

This is one measure for evaluating the transmission quality of digital transmissions. It indicates the probability that the transmitted codes may be incorrectly identified.

Blooming

A phenomenon in which the photoelectrically converted signal charge in an image sensor exceeds a certain level and spills over into adjacent pixels or transfer region other than photodiodes (in IT type CCDs). In CCDs, the spill-out charge appears in the image as a vertical stripe occurring from the light incident position the same as with "smear." To prevent blooming, some means for discharging excess charge should be implemented. In CCDs, this blooming is suppressed by using a vertical/horizontal anti-blooming or clocking method.

Breakdown voltage

As the reverse voltage applied to a PN junction is raised, an abrupt increase in reverse current occurs at a certain voltage. This voltage is called the breakdown voltage. As a guide for convenience when evaluating our Si APD, the voltage that produces a reverse current of 100 µA is specified as the breakdown voltage.

Bump

A solder or other metal protrusion. Bumps are used for three-dimensional mounting. Mounting using fine-pitch bumps allows devices to be smaller and more sophisticated.

C

CDR (clock and data recovery)

A device for recovering a clock and data. Data output from a CDR is not exactly the same as the input data, and is synchronized with the timing of the recovered clock.

CDS (correlated double sampling)

A signal processing method most commonly used for reducing readout noise in a CCD. The CCD signal output detected with an FDA contains kTC noise originating from the detection node capacitance. The kTC noise is also referred to as thermal noise and is always generated by reset operation in a charge-to-voltage converter device like a CCD. The kTC noise in the output can be reduced by using CDS which detects the difference in voltage levels before and after the signal charge flows. CDS is also used to reduce noise in CMOS image sensors.

CMRR (common-mode rejection ratio)

The CMRR expresses the capability of a differential amplifier circuit and the like having two inputs to reject common-mode signals (including noise components) in two input signals. Amplifiers with a higher CMRR can detect smaller signal variations on common-mode signals. As such, it is used as an indicator for the detection capability of balance detectors that are used to detect low-level light signals such as in OCT (optical coherence tomography).

Compton scattering

The phenomenon in which X-rays, gamma-rays, and the like are scattered and part of their energy is lost when they collide with particles (e.g., electrons). This phenomenon is known as indicating particle properties of X-rays and the like.

Crosstalk

A phenomenon in which an electrical signal generated in an element by an incident light signal leaks out into adjacent elements.

In an MPPC, a carrier excited in an APD pixel by an incident photon is multiplied in the avalanche process. During this process, photons different from the incident photon might be generated. If these photons are detected by other APD pixels, then the MPPC output will be higher than the number of photons that actually entered the MPPC and were detected. This phenomenon is thought to be one cause of crosstalk in the MPPC.

Cutoff frequency

The frequency at which the output of a device decreases by 3 dB from the constant output at lower frequencies. The relation between the cutoff frequency (fc) and the rise time (tr) is approximately expressed by the equation below.

$$tr\ [s] = \frac{0.35}{fc\ [Hz]}$$

D

Dark count

In an MPPC or APD used in Geiger mode, thermally generated dark current carriers are amplified and output as dark pulses. These dark pulses are one cause of detection errors. The number of dark pulses per second is the dark count [unit: cps (counts per second)]. Although increasing the reverse voltage improves detection efficiency, it also increases the dark count. The dark count can be reduced by lowering the temperature.

Dark current

A small current which flows when a reverse voltage is applied to a photodiode even in a dark state. This current is called the dark current. Noise resulting from dark current becomes dominant when a reverse voltage is applied to photodiodes (e.g., PIN photodiodes).

DBR (distributed Bragg reflector)

This is a reflector containing a diffraction grating having a cycle of λ/2n (λ: wavelength in vacuum, n: refractive index of medium) formed outside the light emission region in light-emitting devices such as LEDs and semiconductor lasers in order to selectively reflect the light of wavelength λ. In RC type LEDs, forming DBR layers as the upper and lower layers of the light-emitting layer at an appropriate distance causes resonance only at a specific wavelength, so the laser beam can be emitted in the direction perpendicular to the surface. In some LEDs, a DBR layer is formed underneath the light-emitting layer to increase the light level.

Dielectric mirror

A mirror with high reflectance at a specific wavelength band. It has a multilayered structure in which dielectric films with high and low refractive indices are layered alternately.

Diffraction grating

An optical element designed to obtain a spectrum by making use of light diffraction. There are two types of diffraction gratings: reflective and transmissive. Reflective diffraction gratings usually have a great number of grooves formed in their surfaces and utilize diffraction images created by interference with light beams reflected from the grating surface.

Double-heterostructure

A structure where a low-band-gap energy semiconductor material is sandwiched between high-band-gap energy semiconductor materials. Since carriers are confined in the low-band-gap region (emission region), the carrier density increases to allow efficient electron-hole recombination.

E

E detector, ΔE detector

The E detector is a detector with a thickness enough to cover the range of high energy particles. It is designed for detecting the total energy of a particle. The ΔE detector in contrast is made thin enough to allow the particles being detected to pass through it so that the specific energy loss in the particle can be detected. A combination of a ΔE detector and E detector is called the ΔE-E detector and is an effective means of identifying particles.

Ethernet

Ethernet is one of several computer network standards. This was devised by Xerox and standardized by the IEEE 802.3 committee. This is the most common LAN (local area network) standard and is widely used in offices and homes all over the world.

eV (electron volt)

Energy acquired by an electron when it is accelerated through a potential difference of 1 V in a vacuum. This is generally used as a unit to express the energy of elementary particles, atomic nuclei, atoms, molecules, etc.

$1\ \mathrm{eV} = 1.602 \times 10^{-19}\ \mathrm{J}$

Excitation

In semiconductors, excitation refers to the process of raising electrons from a low-energy valence band to the higher-energy conduction band. If electrons are excited by heat, this process is called thermal excitation. If an electron is excited by light, then this process is called photoexcitation. It occurs when light is absorbed by a photodiode.

Extinction ratio

The ratio of the minimum value to the maximum value in the light power that varies during intensity modulation of light waves. In digital optical communications, this is defined as the ratio of the light power for transferring logic "1" to the light power for transferring logic "0." This extinction ratio is expressed in either linear ratio, dB, or %.

[Extinction ratio in digital optical communications]

Extinction ratio (linear ratio) = I(1)/I(0)

Extinction ratio [dB] = 10 log10 {extinction ratio (linear ratio)}

Extinction ratio [%] = I(0)/I(1) × 100

I(1): light power for transferring logic "1"
I(0): light power for transferring logic "0"

Eye diagram

This is a superimposed display of all waveforms for possible encoded strings, used to perform a comprehensive evaluation of the waveform distortion of the transmitted encoded pulses. This is also called the eye pattern.

F

Fano factor

Average number (J) of electron-hole pairs generated in a crystal by incident radiation is expressed by the following equation:

$$J = \frac{E}{\varepsilon}$$

E: energy of radiation
ε: average energy required to generate an electron-hole pair

In this case, the standard deviation (σ: Fano noise) which represents statistical fluctuations in the number of electron-hole pairs is expressed by the following equation:

$$\sigma = \sqrt{F J}$$

F in this equation is a coefficient for correcting deviations from the Poisson distribution and is called the Fano factor.

FDA (floating diffusion amplifier)

A low-noise readout method most commonly used for a CCD output section. Hamamatsu CCDs use this FDA.

Fill factor

This is the ratio of the "effective area excluding the insensitive area (e.g., wiring section)" to the entire area such as the photosensitive area.

Flip chip bonding

A technique for bonding a chip with bumps attached to the electrodes on the upper surface of the chip, by placing the chip upside down onto a package or another chip to make electrical connections. Chip-on-chip mounting allows much smaller assembly.

FOP (fiber optic plate)

An optical device made up of a bundle of optical fibers whose diameter is several microns. It is a substitute for a lens and transfers light and images with high efficiency and low distortion. FOPs do not require a focal distance as with a lens, and this makes compact optical design possible.

FOS (fiber optic plate with scintillator)

An FOP plate with a CsI(Tl) scintillator for X-rays.

FWHM (full width at half maximum)

This is used to describe the degree of spreading of a normal distribution (Gaussian distribution) or the like. FWHM is the full width at half (1/2) maximum of a normal distribution.

G

Gain

When carriers (electrons or holes) are excited by incident photons, the gain is expressed as the ratio of the number of carriers that are output after being multiplied, to the number of the excited carriers.
In the case of an APD, the gain M is defined as the ratio of the photocurrent Ip multiplied by application of a high reverse voltage to the photocurrent I_{P0} generated at a low reverse voltage not causing a multiplication.

$$M = Ip/Ip_0$$

In the case of an MPPC, the gain M is the ratio of the charge of one output pulse divided by the charge of one electron.

$$M = \text{Charge of one output pulse}/q$$

q: electron charge

Geiger discharge

When an APD is operated at a reverse voltage higher than the breakdown voltage, saturation output specific to the element is generated by incident light, regardless of its light level. This phenomenon is called Geiger discharge.

Geiger mode

Operation mode in which an APD is operated at a reverse voltage higher than the breakdown voltage. Geiger mode operation makes it possible to detect single photons.

H

Hysteresis

A phenomenon in which the output level of a device measured while the input level is increased does not equal the output level measured while the input level is decreased, even if at the same input level. Because of this phenomenon, noise within the hysteresis width does not cause chattering. Hysteresis circuits used in a comparator make use of this effect by feeding back part of the output to the non-inverted input terminal.

I

I^2C (inter-integrated circuit)

A serial interface developed by Philips Electronics. The I^2C, pronounced "I-squared-C" or "I-two-C," allows information transfer between ICs by using two signal lines that are SCL (serial clock) and SDA (serial data) lines. The I^2C is used in electronic appliances, cell phones, digital cameras, and audio equipment, for example, when connecting a low-speed (several hundred kilohertz) peripheral device to microcontrollers.

Integration capacitance

Because signal processing is not easy in current-output type NMOS linear image sensors, their output is converted to a voltage output that has low noise and is easier to process by using an inverted input op amp circuit with a feedback capacitance (Cf) added. This feedback capacitance is called the integration capacitance. Periodically resetting the integration capacitance provides a voltage output (V = Q/Cf) converted from an electric charge (Q). The smaller the integration capacitance, the larger the output voltage will be.

Integration time

In image sensor operation, the electric charge generated by light entering in a given time is accumulated and collected to create a signal. The length of this time during which light enters the image sensor is called the integration time or accumulation time. This is usually in the order of milliseconds (ms) but may extend to several hours in cooled type image sensors. In image sensors with a shutter function, the integration time can be set to the order of microseconds (μs).

Interelectrode resistance

This is the resistance between the opposing electrodes of a PSD when it is in a dark state. The interelectrode resistance is an important factor that determines the response speed, position resolution, and saturation photocurrent. The interelectrode resistance is measured with 0.1 V applied across the output terminals of the opposing electrodes while the common electrode is left open. When measuring the interelectrode resistance of a two-dimensional PSD, the output terminals other than the output terminals of the opposing electrodes are also left open.

Ionization rate

In an APD or other similar devices, electron-hole pairs are generated when the accelerated electrons and holes collide with the lattice while moving. The ionization rate is the number of these generated electron-hole pairs per unit distance. Units are in "per centimeter."

L

Linearity

When light strikes a photodiode, a photocurrent is generated in proportion to the incident light level. This proportional relationship between the photocurrent and incident light level is called the linearity. If the incident light level becomes higher than a certain level, then the linearity begins to deviate, causing the photocurrent in the photodiode to saturate. The light level causing saturation depends on the photodiode structure and also varies according to the load resistance, reverse voltage, and the size of the incident light spot.

Lookup table (LUT)

A data structure that replaces a complicated calculation process with a simple array for economizing the process. The calculation processing time can be reduced by storing an array of precalculated values and extracting the necessary data from the matrix as needed.

LVDS (low voltage differential signaling)

This is one of the high-speed digital interface technologies. It features high-speed signal transfer, low noise, resistive to external noise, and low power consumption.

M

MBE (molecular beam epitaxy)

An epitaxial growth technology for forming a thin-film crystal on a heated substrate crystal by supplying molecular beams of crystal-constituent elements, which are created by evaporating each element from separate cells in an ultra-high vacuum.

MCA (multichannel analyzer)

An instrument that displays the heights of multiple input pulses as a histogram.

MEMS (micro-electro-mechanical systems)

A compact three-dimensional system processed using micromachining technology. The basic process technology is the semiconductor lithography for integrating electronic circuits but also includes silicon deep reactive ion etching, sacrificial etching, bonding, and other technologies for fabricating rugged shapes and hollow structures. Representative devices include microactuators and microsensors. Some devices integrate electronic circuits such as CMOS.

Minimum sensitivity, Maximum sensitivity

The minimum and maximum light input powers required to acquire bit error rates within a certain level. The values differ depending on the transmission bit rate, the required bit error rate, the type of pseudo-random codes used for measurement, the extinction ratio, and so forth. The maximum sensitivity is also called overload.

MOCVD (metal organic chemical vapor deposition)

An epitaxial growth technology for forming a thin-film crystal on a heated substrate crystal by thermally decomposing and chemically reacting an organic metal supplied in the form of vapor, which is solid or liquid at normal temperatures and pressures.

MOEMS (micro-opto-electro-mechanical systems)

Compact optics systems using MEMS technology. Also called optical MEMS. Applications include thermal type detectors that make use of hollow structures produced with MEMS technology and optical scanners and optical switches that control the direction of light travel using microactuators. They are also applied to wavelength variable filters and optical interferometers that take advantage of MEMS feature that enables precise position control.

MOST (Media Oriented Systems Transport)

An in-vehicle network standard mainly used in European vehicles. This is a ring type network using POF (plastic optical fibers), and its internode communication speeds are 25 Mbps and 150 Mbps. Besides in-vehicle applications, MOST is used for interphone networks in airports and the like.

MPP (multi-pinned phase) operation

MPP is an operation mode in which all CCD channels under the MOS structure gates constituting the CCD electrodes are reversed. This mode is also called reverse operation and reduces the dark current because it drastically suppresses the generation of thermally excited electrons at the silicon-silicon dioxide interface.

Multimode fiber

An optical fiber for transmitting light in multiple transverse mode (electromagnetic field distribution). Multimode fibers are not suitable for long-distance transmissions because the transmitted waveform is distorted due to differences in the signal light arrival time depending on the mode (modal dispersion). Compared to single-mode fibers, the core diameter is large so that connecting to a light emitter is easy. However, condensing a light beam onto a light receiver element for high-speed communication is difficult because the element must have a small photosensitive area.

N

NDIR (non dispersive infrared) detection method

A method of detecting infrared light at specific wavelengths by using a band-pass filter, instead of a grating or some other means to diffract light. Non-dispersive infrared detection methods are characterized by their simple structure. Certain gases such as carbon dioxide have absorption peaks at specific infrared wavelengths. It is possible to measure the components and concentration of a gas mixture by running the gas between an infrared light source and detector and examining the level of absorption at different wavelengths.

NEP (noise equivalent power)

NEP is the incident light level equivalent to the noise level of a device. In other words, it is the light level required to obtain a signal-to-noise ratio (S/N) of 1. We define the NEP value at the peak sensitivity wavelength (λp). Since the noise level is proportional to the square root of the frequency bandwidth, the bandwidth is normalized to 1 Hz.

$$\text{NEP } [\text{W/Hz}^{1/2}] = \frac{\text{Noise current } [\text{A/Hz}^{1/2}]}{\text{Photosensitivity } [\text{A/W}] \text{ at } \lambda p}$$

O

Open circuit voltage

A photovoltaic voltage developed in a photodiode when the load resistance is infinite. This open circuit voltage depends on the light level but is nearly constant at fairly low and higher light levels.

Open-loop gain

This is the gain of an operational amplifier with no feedback applied, and represents the ratio of the output voltage to the input voltage. Units are in dB.

Optical return loss (ORL)

The ratio of the reflected return light to the incident light. If the reflected return light level is high, the laser diode oscillation on the transmit side will become unstable causing relative intensity noise to increase. The reflected return light level must therefore be minimized. As solutions for this problem in receptacle type modules, an optical isolator, or a ferrule called a "stub" (component with the fiber insertion side polished for physical contact and the device side polished slantwise) is often inserted in the optical path to minimize the optical return loss.

P

p.e. (photon equivalent)

This represents the detection level per photon. A 1 p.e. pulse, for example, is equivalent to the pulse obtained when one photon is detected.

Passive alignment

Positioning method in which only mechanical precision is relied upon for coupling two or more optical elements during optical module assembly. Since the positioning of optical elements usually requires accuracy ranging from submicrons to several microns, highly precise metalization patterns, V-grooves, and the like formed by semiconductor process technology are utilized as the positioning reference.
In contrast to passive alignment, active alignment performs the positioning of optical device and fiber while making the optical modules emit light by simulating actual operation (for instance, operating a laser diode to emit light) and monitoring the emitted light in order to obtain the required characteristics of the optical modules.

Phosphor sheet

Phosphor sheet has fluorescent powder particles (the same as scintillators) hardened with resin on a support film layer. It is used for radiation detection of relatively low-energy X-rays and the like. Phosphor sheet is attached to image sensors for X-rays for use.

Photoconductive detector

A photosensor which increases its electric conductivity when illuminated with light. An external power supply is needed to operate a photoconductive detector. Photoconductive detectors include MCT (HgCdTe), PbS, and PbSe.

Photoelectric effect

A phenomenon in which a substance absorbs light and generates free electrons.

Photon detection efficiency (PDE)

This is a measure of what percent of the incident photons were detected.
In the case of MPPCs, PDE is expressed by the following equation. The avalanche probability (Pa) becomes larger as the reverse voltage is increased.

$$\text{PDE} = \text{QE} \times \text{fg} \times \text{Pa}$$

QE: quantum efficiency
fg : geometric factor (fill factor)
Pa : avalanche probability

Photosensitivity

The ratio of photocurrent expressed in amperes (A) or output voltage expressed in volts (V) to the incident light level expressed in watts (W). Photosensitivity is represented as an absolute sensitivity (A/W or V/W) or as a relative sensitivity (%) to the peak wavelength sensitivity normalized to 100. We usually define the spectral response range as the range in which the relative sensitivity is higher than 5% or 10% of the peak sensitivity.

Photovoltaic detector

A semiconductor photosensor generating an electrical current or voltage when light is illuminated on its PN junction. It is capable of operating without power supplied from an external source. Photovoltaic detectors include Si, InGaAs, GaAsP, GaAs, InAs, InAsSb, and InSb.

Position detection error

When a light spot irradiates onto a PSD and the resulting current extracted from each output terminal of the PSD is equal, the incident position of the light spot is called the electrical center of the PSD. By considering this electrical center as the origin, the position detection error is defined as the difference between the position at which the light spot is actually incident on the PSD and the position calculated from the photocurrents. We measure the position detection error under the following conditions:

· Light source: λ=890 nm
· Light spot size: ϕ200 μm
· Photocurrent: 10 μA

Position resolution

The minimum detectable displacement of a light spot incident on the photosensitive surface of a PSD, expressed as a distance on the photosensitive surface of the PSD. This position resolution is determined by the S/N, which is calculated by: PSD resistance length × noise/signal. We define the position resolution calculated based on root-mean-square (rms) noise measured under the following conditions:

· Interelectrode resistance: See characteristic table in our datasheets.
· Photocurrent: 1 μA
· Frequency bandwidth: 1 kHz
· Equivalent input voltage noise of circuit: 1 μV

Power dissipation

The maximum power consumption allowed for a device, calculated from the upper temperature limit of the package and chip. In most cases, this is determined by heat-vulnerable components included in the device. Using a coefficient called "derating" makes it possible to calculate the absolute maximum rating for the power dissipation at the temperature at which the device will actually be used. For example, if a power dissipation of 500 mW is defined as the absolute maximum rating at 25 °C and the derating is 5 mW/°C, then the absolute maximum rating at 85 °C will be: 500 mW - 5 mW/°C × (85 °C - 25 °C) = 200 mW.

Propagation delay time

The time required for a signal to travel from the transmitted or input point to the received or output point. This term generally indicates the total of the delay time in the circuit and optical elements and the delay time in a medium (e.g., optical fiber). The propagation delay time that changes is termed the jitter or wander. Jitter is the fluctuation in propagation delay time that occurs in a short period of time and mainly results from noise. Wander is a long-term fluctuation chiefly caused by thermal factors.

Pseudo-random pattern

An encoded string that is seemingly irregular (not truly irregular) and is used to measure bit error rates and eye patterns. In commonly used pseudo-random patterns, the event probability between 0 and 1 is equal so that a pseudo-random pattern can be relatively easily generated by a circuit that uses a shift register and feedback.

Q

Quantum efficiency

This is the number of electrons or holes that can be extracted as photocurrent divided by the number of incident photons. It is commonly expressed as a percentage. The quantum efficiency QE and photosensitivity S (unit: A/W) have the following relationship at a given wavelength λ (unit: nm).

$$QE = \frac{S \times 1240}{\lambda} \times 100 \ [\%]$$

Quenching

Quenching means extinction or rapid cooling. In an APD operated in Geiger mode, quenching is a technique to stop Geiger discharge by reducing the reverse voltage below the breakdown voltage.

R

Rise time

The rise time is the time required for the output to rise from 10% to 90% of the maximum output value (steady-state value) in response to input of step-function light.

S

Scintillator

A material that emits light when exposed to radiation such as X-rays. Scintillators are divided into inorganic and organic scintillators. Well-known inorganic scintillators are crystals or powder of CsI (cesium iodide) doped with a small amount of activator such as Tl (thallium) to enhance the emission efficiency. Organic scintillators include naphthalene, anthracene, plastic, liquid scintillator, and lumogen. The lumogen is a material that emits light in response to UV rays, and is therefore sometimes coated on front-illuminated CCDs having no UV sensitivity.

Seebeck effect

An effect in which a potential difference (electromotive force) appears between the ends of two different metals or the like when there is a temperature difference between the hot junction side and cold junction side of the two different metals or the like.

Short circuit current

This is the output current that flows in a photodiode when load resistance is zero. This is called "white light sensitivity" to differentiate it from the spectral response, and is measured with light from a standard tungsten lamp at 2856 K distribution temperature (color temperature). Our datasheets list the short circuit current measured under an illuminance of 100 *lx*.

Shunt resistance

This is the voltage/current ratio of a photodiode operated in the vicinity of 0 V. In our datasheets, the shunt resistance is specified by the following equation, where the dark current (I_D) is a value measured at a reverse voltage of 10 mV.

$$Rsh\ [\Omega] = \frac{0.01\ [V]}{I_D\ [A]}$$

Noise generated from the shunt resistance becomes dominant in applications where a reverse voltage is not applied to the photodiode.

Single-mode fiber

An optical fiber designed to transmit light in the single transverse mode (electromagnetic field distribution). Single-mode fibers have low transmission loss and are not affected by modal dispersion, making them suitable for long-distance transmission. However, they require precise core alignment when connecting to a light emitter since their core diameter is small.

Smear

In image sensors, smear is a phenomenon where a signal charge generated by intense input light leaks to the adjacent pixels or CCD transfer region and causes the original signal to become smeared (blurred). In contrast to "blooming" that occurs following saturation, smears occur even before saturation. Smears tend to occur from light at longer wavelengths rather than light at shorter wavelengths.

Snell's law

Light passing through an interface between two media (such as air and glass) with different refractive indices is refracted, which causes the direction of light travel to change. Snell's law describes the relationship between the light's angle of incidence q (the angle between the normal of the interface and the incident ray) into the interface and the angle of refraction q' (the angle between the normal of the interface and the refracted ray). It is expressed by the following equation.

$$n \sin q = n' \sin q'$$

n: refractive index of the medium on the incident side
n': refractive index of the medium on the refractive side

SOA (semiconductor optical amplifier)

An optical amplifier using a semiconductor. The structure is very similar to a Fabry-Perot laser diode but is designed not to cause reflection at the edge. SOA enables amplification over a wide spectral range and requires fewer components than EDFA, which makes the amplifier device smaller and reduces power consumption.

SONET/SDH

These are international standards for high-speed digital communication methods using optical fibers. SONET (Synchronous Optical Network) is a North American standard specifications established by ANSI (American National Standards Institute). SDH (Synchronous Digital Hierarchy) is an internationally standardized interface by ITU (International Telecommunication Union) based on SONET. Although differing on some minor points, SONET and SDH can be considered as nearly the same standard and allow interconnections with each other. SONET is well-known in North America, while SDH is mainly used in Europe.

Space charge effect

When light incident on a photosensor is blocked, the carrier distribution in the depletion layer is disturbed. The carriers are then drawn to the electrodes and generate an electric field in the depletion layer in the direction opposite to the applied bias voltage. This phenomenon is referred to as the space charge effect and might degrade the response characteristics (fall time) when the incident light level is high.

Spatial resolution

The ability of an image sensor to faithfully capture the details of an object. MTF (modulation transfer function) is usually used to evaluate the resolution of an image sensor. When an object with a sine-wave brightness distribution is imaged, the MTF indicates how the sine-wave brightness contrast varies with the spatial frequency. The spatial frequency is the number of times that a sine wave is repeated per unit length. Since the photosensitive area of a CCD consists of discrete pixels, CCDs have a limiting resolution determined by the Nyquist limit based on the discrete sampling theorem. For example, when a black-and-white pattern is viewed with a CCD, the difference between the black and white signal levels decreases as the pattern becomes finer, and finally reaches a point at which the pattern can no longer be resolved. The ideal MTF is expressed as follows: sinc* $\{(\pi \times f)/(2 \times fn)\}$ (f: spatial frequency, fn: spatial Nyquist frequency). However, because of the difficulty in creating an optical sine wave, a rectangular-wave response test chart is generally used instead. In this case, the spatial frequency characteristic is called the CTF (contrast transfer function).

* sinc: Fourier transform of an ideal rectangular function

Spectral response

The relation (photoelectric sensitivity) between the incident light level and resulting photocurrent differs depending on the wavelength of the incident light. This relation between the photoelectric sensitivity and wavelength is referred to as the spectral response characteristic and is expressed in terms of photosensitivity or quantum efficiency.

Stealth dicing

Stealth dicing is a new dicing method developed by Hamamatsu. It uses a laser beam to form a modification layer inside a wafer and cut the wafer into chips with high quality. Since light that transmits into the material is used, no thermal damage occurs on the wafer surface. Stealth dicing does not produce any cutting loss, so the chip yield per wafer can be increased to the maximum. There is absolutely no contamination such as from flying debris which is unavoidable in conventional dicing techniques, and stealth dicing is a completely dry process because no cleaning water is required.

T

TAC (time-to-amplitude converter)

An instrument that outputs the time difference between two pulse signals as a pulse amplitude (height).

Terahertz wave

Electromagnetic waves at frequencies around 1 THz (wavelength: 300 µm). Terahertz waves transmit through paper, wood, and plastic but do not transmit through metal and water. The terahertz band is called the fingerprint region of substances.

Terminal capacitance

In a photodiode, the PN junction can be considered as a type of capacitor. This capacitance is termed the junction capacitance and is an important parameter in determining the response speed. In current-to-voltage conversion circuits using an op amp, the junction capacitance might cause gain peaking. At Hamamatsu, we specify the terminal capacitance including this junction capacitance plus the package stray capacitance.

Thermistor

A thermally sensitive resistor that greatly changes its electrical resistance as the temperature changes. Thermistors are used for temperature sensing.

Thermoelectric conversion material

Material for converting heat into electricity. It makes use of the Seebeck effect, which describes how electromotive force is generated when the two ends of two different metals or semiconductors joined together are at different temperatures.

Thermoelectric cooler

When an electric current flows through the junction of two dissimilar electric conductors, heat absorption (or heat generation) occurs on one side while heat generation (or heat absorption) occurs on the other side. Thermoelectric coolers make use of this effect (known as Peltier effect). Reversing the direction of the electric current reverses the relation between the heat absorption and generation.

Tiling

An arrangement of two or more photosensors in a tile configuration to have a wider photosensitive area. Also called "buttable."

Tracking detector (vertex detector)

A detector mainly used in elementary particle energy physics experiments for the purpose of tracking the traveling direction and decay processes of secondary particles generated as a result of high energy particle collisions. Tracking detectors are installed at positions surrounding the point where the particles collide.

V

VICS (Vehicle Information and Communication System)

An information communication system in Japan that transmits road traffic information such as traffic jams, road construction, road regulations, and time required to reach destination to in-car navigation equipment and the like. Information from optical beacons installed on major trunk roads and from radio-wave beacons installed along highways as well as wide-area information of specific prefectures by FM multiplex broadcasting are transmitted to the cars in real time.

W

WDM (wavelength division multiplexing)

WDM is a method for multiplexing multiple data on single-core optical fiber cable by changing the wavelength of the carrier wave. There are two modes depending on the multiplexed density: DWDM (dense wavelength division multiplexing) and CWDM (coarse wavelength division multiplexing). DWDM typically uses eight or more wavelengths in the 1.55 µm band (some use the 1.3 or 1.6 µm band) that are densely arranged at wavelength intervals from 0.4 to 3.2 nm. In contrast, CWDM uses two to eight wavelengths spaced at wavelength intervals ranging from 20 to several hundred nanometers.