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Progress Through Photonics

Pulsed Laser Diodes and Avalanche Photodiodes for Industrial and Commercial Applications

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With the help of pulsed laser diodes and avalanche photo diodes distances can be measured precisely, quickly, and without contact for a range of optoelectronic applications. Depending on the system performance und life time requirements, the emitter side incorporates either single emitters or stacks whereas on the receiver side APDs with different structures are used.

Pulsed laser diodes (PLDs) and avalanche photo diodes (APDs) have their roots in military applications. Thanks to PLD peak powers of more than 200 W and the high sensitivity of APDs they are ideally suited for range finding based on the "time of flight" method. Improvements in technology and cost efficiency have opened up new areas of industrial, commercial, and automotive applications.

Pulsed laser diodes

Most laser diodes are designed to emit in a continuous wave (cw) mode with powers from a few milliwatts to a few watts. Such diodes are not designed to be overdriven; if the specified maximum power is exceeded, even for a short time, the laser resonator may be damaged, after which laser output will cease.
Pulsed laser diodes, however, are designed to be overdriven for short periods of time. To achieve the high peak powers demanded by the application, the duty cycle must be kept very low, typically at 0.1%. For example, a 100-ns pulse is followed by a pause of 100 ms, which means that very short pulses can be used with repetition rates in the kHz range. The maximum pulse lengths typically in the range of a few 100 ns. Laser currents on the order of several tens of amperes are used that can be achieved are therefore to create these light pulses, which require fast switching transistors and appropriate circuits with all electrical connections as short as possible to diminish inductive losses.

Fig. 1:
Pulsed Laser diodes and Avalanche Photodiodes of various housing types.

The emitted wavelength is an important criteria when choosing a pulsed laser diode. The emission wavelength of a laser diode depends primarily upon the materials used in the active and passive layers of the semiconductor. Typical wavelengths for commercially available pulsed laser diodes are 850 – 870 nm, 905 nm, and 1550 nm. The AlGaAs structure of the 905 nm devices is well known for its reliability, beam characteristics, and temperature stability. The high efficiency of 1 W/A allows powers of up to 40 W to be reached with single emitters, and of up to 220 W for stacked devices with pulse lengths of 100 ns. For shorter pulses "light bolts" of more than 500 W are possible. The advantage of this wavelength is that the maximum spectral sensitivity of Si APDs falls exactly into this spectral range. The 1550 nm devices available in the mid-IR can be operated at higher peak power than the 905 nm devices and still be regar ded as eye safe since the laser radi ation is not focused directly on the retina.
These diodes are based on InP with additional InGaAsP layers, and can be manufactured either by molecular beam epitaxy (MBE) or metalorganic chemical vapor deposition (MOCVD). Peak output powers of up to 50 W at pulse lengths of 150 ns can be reached using stacked devices thanks to the efficiency of 0.35 W/A. Due to heat sinking issues these devices are typically only available in 9-mm or TO-18 packages whereas PLDs at 850 – 870 nm and 905 nm are also available in inexpensive plastic packages.

Apart from the wavelength and electro-optical specifications, reliability is an important criterion for selection. As with other light sources, especially semiconductor lasers, the lifetime of a pulsed laser diode is highly dependent on operating conditions. Without damage, the devices can be subjected to significant overdrive for short periods of time or when the pulse energy is reduced by employing pulse durations as short as just a few ns. The user should choose the appropriate device and drive conditions to suit the application and the operating lifetime required. Whereas lifetimes of less than an hour are enough for certain military applications, such as thyristor ignition, industrial safety scanners in three-shift environments need to run reliably for tens of thousands of hours.

The following formula was derived from many years of experience with pulsed laser diodes and gives an indication of mean time to failure (MTTF) as a function of a range of parameters:

$$MTTF = k \cdot (P/L)^{-6} \cdot t_w^{-2} \cdot F^{-1} \cdot f(T)$$

where MTTF is the mean time to failure in hours, k is a material- dependent constant, e.g. $1.14 \cdot 10^{20}$ for 905 nm PLD by Laser Components, P is the optical peak power in mW, L is the emitter length in mm, t_w is the pulse length in ns, F is the repetition rate in kHz and f(T) is a temperature-dependent multiplying factor (= 1 at 25 °C).

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Avalanche Photodiodes
Measurement systems use either PIN diodes or APDs on the receiver side to detect the short light pulses of PLDs. Lifetime considerations for these parts are secondary because they virtually last forever, pending correct handling.
In conventional photodiodes, incoming photons create electron- hole pairs, also called charge carriers, that supply a measurable photocurrent. The power of the incoming photons has been transformed into electrical energy. Here, APDs have taken a significant step forward. APDs differ from "normal" PIN photodiodes in that incoming photons internally trigger a charge avalanche. The prerequisite for this is the application of reverse bias voltage to the APD to broaden the absorption layer "A." In the APD, the charge carriers set free by the light are accelerated in the electrical field in such a manner that they produce further electron-hole pairs through impact ionization. If the reverse bias voltage is less than the breakdown voltage, the avalanche will die down again due to friction losses. To this point a single photon has generated hundreds or even thousands of electrons. Above the breakdown voltage, the acceleration of the charge carriers is high enough to keep the avalanche alive. A single photon can be sufficient to generate a constant current which can be measured by external electronic equipment. The current generated is calculated as follows:

$I = R_0 \cdot M \cdot P_s$

whereby R_0 (A/W) is the spectral responsivity of the APD, M is the internal gain and P_s (Watt) the incident optical power. The gain of the APD depends on the reverse bias voltage applied (see Fig. 2). When choosing a suitable APD the lifetime is, as mentioned above, secondary. The spectral range, the detector area, the internal noise properties, and the system bandwidth are more important. APDs are available in the range from 300 nm to 1700 nm. Silicon APDs are, depending on their structure, suitable between 300 nm and 1100 nm, germanium between 800 nm and 1600 nm, and InGaAs from 900 nm to 1700 nm. Silicon offers the most extensive APD product range. Depending on the manufacturing process, various parameters offering advantages for individual applications can be achieved. An overview of the most important specifications can be found in Table 1. Compared to germanium APDs, InGaAs APDs have significantly lower noise characteristics, a higher bandwidth relative to the active area, and advantages due to the extended spectral response to 1700 nm. One disadvantage, however, is that InGaAs APDs are more expensive than Ge APDs. Germanium is therefore primarily recommended for cost-sensitive applications or in systems exposed to electromagnetic interference and in which the secondary amplifier noise is significantly higher. It is obvious that small-area APDs are more economical than larger detectors since more chips can be manufactured per wafer. Therefore, the minimum active surface size required to realize the optical structure should first be determined. Sometimes it may be advantageous to use a somewhat larger APD, since special optics for focusing on a small spot may be more expensive than the additional charge for a larger APD. To compare the efficiency of an APD with a PIN diode, it is insufficient to merely compare the noise of the detectors. The signal-to-noise ratio of the entire system is crucial. For PIN diodes, the corresponding preamplifier must also always be considered. Its noise characteristics are, among other things, dependent upon frequency. An APD is superior to a PIN diode whenever the APD can substantially boost the signal level without significantly increasing the overall system noise. Thus, APDs are preferred wherever low light intensities have to be detected at middle or high frequencies. The optimum internal gain is selected when the detector noise is approximately equal to the input noise of the secondary amplifier (or load resistance). The APD therefore does not affect the system noise. Noise increases with the bandwidth of the system for PIN diodes as well as APDs. Thus, it is important to reduce the bandwidth as far as practicable.

Silicon APD Types	Bevelled Edge	Epitaxial	Reach Through
Structure			
„Absorption" Region	large	low	middle to large
"Multiplication" Region	large	low	low
Typical size (diameter)	up to 16mm	up to 5mm	up to 5mm
Gain	50 to 1000	1 to 1000	10 to 300
„Excess noise" Factor	very good	good	good to very good
	(k = 0.0015)	(k=0.03)	(k=0.02 to 0.002)
Operating Voltage	500 to 2000V	80 to 300V	150 to 500V
Rise time	slow	fast	fast
Capacitance	small	large	small
Blue sensitivity (400nm)	good	poor	poor
Red sensitivity (650nm)	good	good	good
NIR sensitivity (905nm)	very good	good	very good

Table 1:
Overview of the various si APD structures and their characteristics

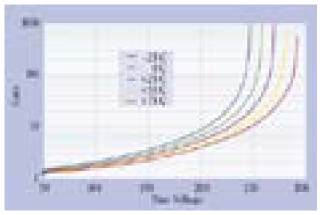

Fig. 2:
Typical gain versus operating voltage for a Si APD where D= 500 μm at different temperatures.

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Applications

The most common application for combining PLD and APD is rangefinding of all sorts based on the “time of flight” method. One example is a speed gun. Using pulse lengths of a few ns and powers of several tens of watts, vehicle speeds of up to 250 km/h may be easily measured. The distance between the fixed installed laser measurement system or the policeman and his speed gun and the passing vehicle can range up to 1000 m. The accuracy of such measurements is typically 1–3 %.
Hunters use eye-safe rangefinders to measure the distance to their targets. Neither the deer the hunter is aiming at, nor anyone else nearby, needs to worry about their eyesight. In this case, the class 1 laser device delivers accurate information within one second, with an accuracy of 2 m at distances of 600 m. In other applications, golfers use laser rangefinders to try to improve their handicaps, and car drivers are warned of approaching hazards or when the car in front is too close (Fig. 3). Laser sensors are also widely used as navigational aids for ships, particularly in ports and harbors, and for cloud base measurement at airports, as well as in surveying and construction when quarries or dumps have to be sized or the height of buildings, trees, and other objects has to be measured. Laser safety scanners, based on pulsed laser diodes and highly sensitive avalanche photodiodes, create a curtain of laser light which senses the presence of persons or objects in potentially dangerous areas, e.g. in automated production lines (Fig. 4).

Summary

Pulsed laser diodes and avalanche photodiodes are perfect for rangefinding applications. The different wavelength and power combinations of the emitter, which are defined by the requirements of the application, will find the corresponding optimal counterparts among the different APD structures. Advances in manufacturing have opened up possibilities for a number of new commercial and industrial applications.

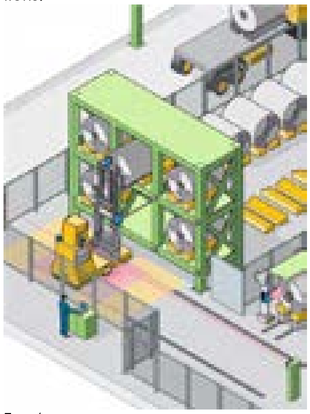

Fig. 4:
Laser safety scanners create a curtain of laser light which senses the presence of persons or objects in potentially dangerous areas (SICK AG, Waldkirch).

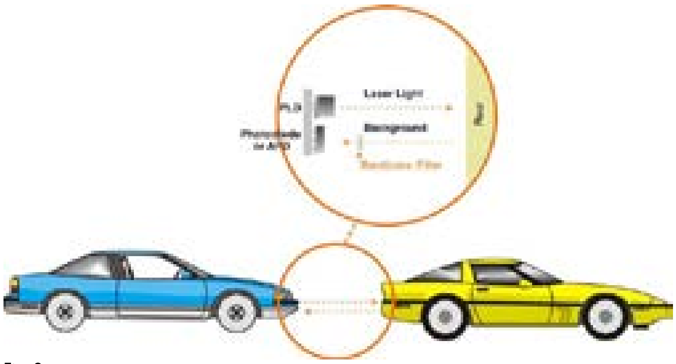

Fig. 3:
Distance and relative speed measurements in the automotive industry with the help of pulsed laser diodes (PLDs) and avalanche photodiodes (APD)

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