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No Conventional Solution

Automotive applications need special LIDAR systems.

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Which is the best lidar technology for automotive applications? There is still no such thing. As a leading component manufacturer, Hamamatsu is well aware of the advantages and disadvantages offered by various systems, and the main differences will be explained in this article.

Whether in factories or cars, the use of smart and autonomous systems is increasing. An important condition for totally safe and functional systems is sophisticated sensors and imaging processes that provide true-to-life images of the surroundings. Advanced driver assistance systems currently employ around a hundred sensors to provide functions such as lane departure warning or automatic distance control. Full accuracy and fast reaction times are essential in this field, even at high speeds and in unforeseen situations.

One of the most promising developments in recent years has been the use of light detection and ranging (lidar) systems, an optical method to measure distance and speed. Unlike the related radar system, lidar sensors identify the environment by means of light, which is detected by a photosensor (**Fig. 1**). But not all lidar systems are the same, and not all photosensors are equal. Which technology is the most suitable depends on the application.

Hamamatsu Photonics, a manufacturer of optical products and semiconductor components, helps to select and assemble the right components as the company's products cover the entire range of lidar technologies.

TOF measurement or FMCW?

There are currently two technological approaches to lidar: time of flight (TOF) and frequency-modulated continuous wave (FMCW), which is based on frequency modulation. While TOF lidars are recognized as the norm, FMCW systems are becoming increasingly popular because they promise to overcome some of the problems of the TOF approach.

The basic principle of TOF lidar is simple (**Fig. 1**): a light source emits a concentrated beam of light that is reflected by an obstacle – such as a pedestrian or a car – and bounces it back to a photosensor. The sensor calculates the distance of the object, based on the time needed by the reflected light to hit the sensor.

Pulsed lasers are often used as a radiation source, which allows the wavelength and polarization state of the pulse to be varied. Commonly, wavelengths ranging from 850 to 1550 nm are used. Lower wavelengths allow the use of silicon detectors, but the light is absorbed more easily and they are more harmful to the human eye, consequently they are not suitable for all applications. Light with a wavelength of 1550 nm is also more suited to penetrate bad weather conditions such as rain or snow. It is better suited for long distance detection and can produce accurate results even at a distance of more than two hundred meters with a reflection of ten percent.

One challenge here is the scattering of the light: only a small fraction of the emitted photons find their way back to the active area of the photosensor. Environmental influences, such as rain or air particles as well as other reflective surfaces, absorb some of the light and reduce the number of photons received. At the same time, photons related to background noise hit the detectors, which can negatively influence the accuracy of the measurement. A filter that is strictly limited to the range of the emitted wavelengths may help, but this background noise cannot be completely prevented, meaning that the accuracy of the lidar reduces with increasing distance.

One method of reducing this problem could be FMCW lidar: instead of light pulses, a continuous, chirped laser beam is emitted, so the frequency of the signal keeps changing. The light beam is reflected by an object and returned to the photodetector. The decisive factor here is not the time itself, but the difference in the frequency of the incoming signal compared to the signal emitted at the same time. Based on this difference, the lidar can determine not only the distance but also the speed of the moving object.

Frequency synchronization requires a bit more computing power than a simple acquisition. Compared to TOF, the FMCW method takes a little more time to create an accurate 3D environment model. Moreover, the technology is also relatively new and consequently often still bulky and expensive. On the other hand, FMCW lidars are less subject to noise and work well over long distances. So the question about the 'best' lidar technology largely depends on the application scenarios and the prevailing conditions. But also the selection of the optimum photosensor is important.

Accuracy vs range?

Lidar applications place high demands on photodetectors. Ideally, they should be sensitive enough to receive a large number of photons without collecting too much extraneous noise. In automotive applications, it is also essential that the sensors respond quickly and with full reliability. They should also be cost-efficient, suitable for mass production and able to tolerate a whole range of different environmental conditions, from temperature fluctuations to changing light conditions.

In any case, the greater the distance from the object to be detected, the lower the accuracy of the measurement. This principle is not equal for all types of photodetectors. Depending on the application, manufacturers can choose from these three types of photosensor.

A **PIN diode** – which has a wide, undoped, intrinsic semiconductor between the p and n regions – is the simplest and most cost-effective type of photosensor. Energy consumption is low, with an operating voltage of up to ten volts. Over short distances, the light sensitivity is high and stable at the same time, and temperature fluctuations hardly affect the performance. The readout range is relatively high and even in strongly illuminated surroundings a PIN photodiode performs well. A transimpedance amplifier is usually used as the readout circuit. But the gain is low, typically around one.

For applications where the light does not have to travel long distances – like some TOF applications – a PIN photodiode is absolutely sufficient and offers the best price/performance ratio. For example, the S13773, a Si PIN photodiode from Hamamatsu Photonics, is suitable for distance measurements in the spectral range 380 to 1000 nm due to its fast response time, but it is not appropriate for longer wavelengths of 1550 nm. Applications with strong ambient light or signi-

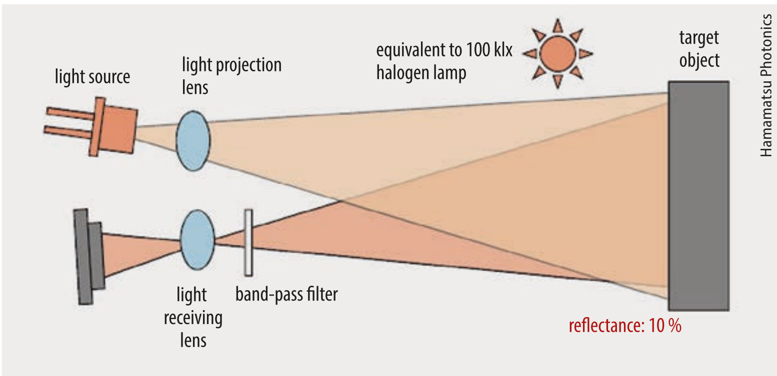

Fig. 1 Lidar concept

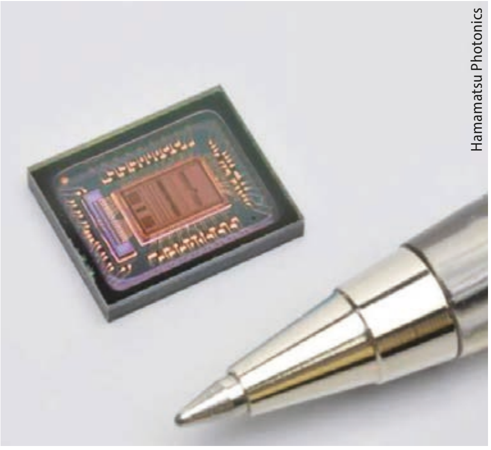

Fig. 2 1D MPPC (SiPM) Array + ASIC

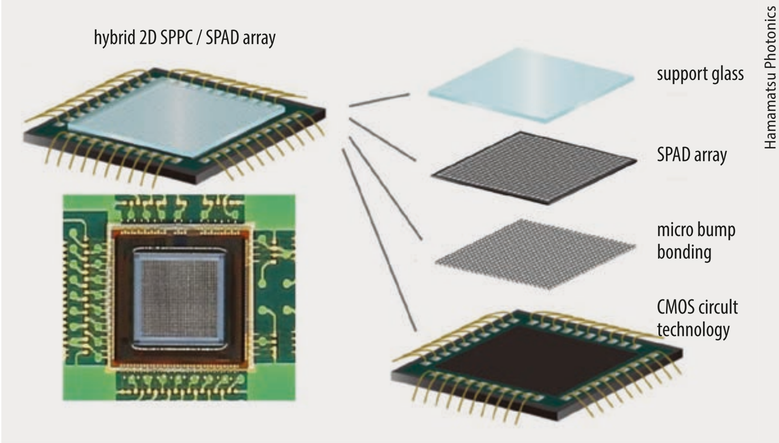

Fig. 3 Hybrid single-photon avalanche diode (SPAD) array

ficant temperature changes also benefit from using a PIN photodiode. The S13773, for example, can tolerate operating temperatures between –40 and +100 °C.

Avalanche photodiodes (APDs) use the avalanche effect to generate internal gain. This achieves gains of around one hundred. However, in order to prevent measurement inaccuracies from background noise, manufacturers usually resort to a bandwidth filter. APDs are also very temperature sensitive and have an operating voltage of 100 – 200 V. In addition to Si APDs, there are also special InGaAs APDs that are specifically designed for a wavelength of 1550 nm (e.g. Hamamatsu's G14858-0020AB).

For a long time, these two variants have been considered standard devices for their respective fields of application. Although APDs are more complex and expensive compared to PIN photodiodes, they are almost indispensable for longer-range applications.

Hamamatsu has recently brought a third candidate into the race: **multipixel photon counters** (MPPCs), also known as silicon photomultipliers (SiPM, **Fig. 2**). They consist of a series of APDs (hereafter referred to as channels) operating in Geiger mode. As a result, an MPPC sensor has significant gain – up to a factor of 10^6 is easily achievable. At the same time, the use of several APDs connected in parallel prevents a loss of information about the number of incident photons. MPPCs are therefore also suitable for single-photon detection and can cope with suboptimal conditions with very weak light incidence. They provide reliable results, even at long distances, granting a short response time. MPPCs are insensitive to magnetic fields and, in terms of temperature sensitivity, they qualify between APDs and PIN photodiodes. Moreover, while MPPCs can be switched via a transimpedance amplifier just like PIN photodiodes or APDs, it is possible to utilize less complex readout circuits, such as high-frequency amplifiers.

In Hamamatsu's new generation of MPPC detectors, the photon detection efficiency has been further improved. This combination of features makes MPPC sensors an attractive alternative for many automotive applications that could previously only be covered by APD sensors. In addition to MPPCs, Hamamatsu will soon introduce 2D SPPC arrays. As with MPPCs, these 'single-pixel photon counters' can cover long-range sensing and have similar detection speed and temperature stability characteristics. The overall system costs could be cheaper than the costs of MPPC modules.

It is then worth pointing out: the road to fully autonomous industrial and automotive applications is rocky and deeply ramified. Individually adapted solutions are key to dealing with this complexity, and the motto "customizations instead of standard solutions" could not apply better to lidar systems. As a one-stop-shop, Hamamatsu can offer both unbiased opinion and advice. They can also supply all components from a photodetector to a laser diode, all from a single source. They can offer pulsed lasers as well as continuous wave lasers with a very accurate near field pattern. All components are perfectly adapted to one another and can be adjusted to the requirements of each individual application.

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