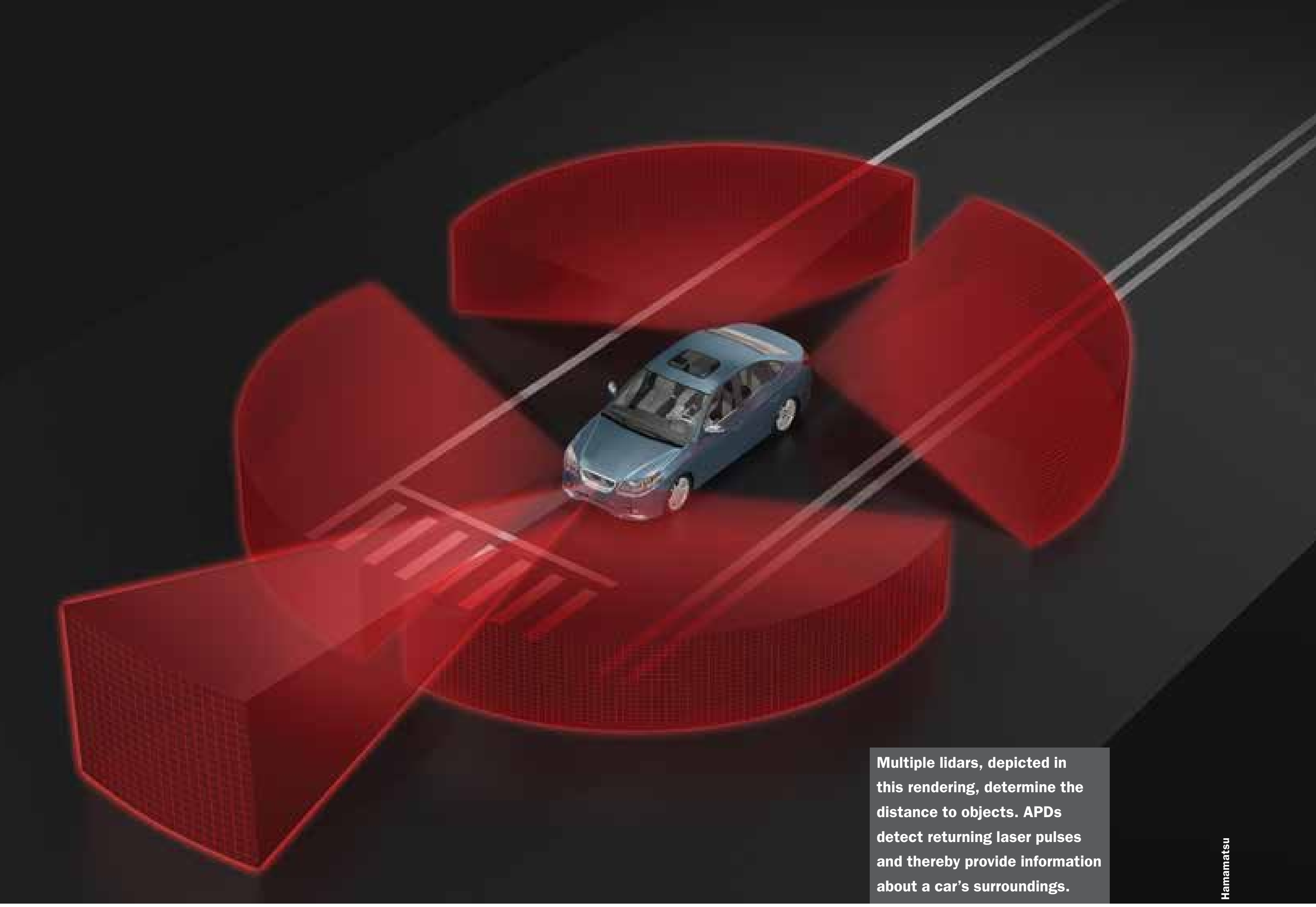


Multiple lidars, depicted in this rendering, determine the distance to objects. APDs detect returning laser pulses and thereby provide information about a car's surroundings.

Hamamatsu

# An Avalanche of **APD** Innovations

As the demands on lidar continue to increase, the manufacturers of avalanche photodiodes (APDs) continue to respond.

BY HANK HOGAN
CONTRIBUTING EDITOR

When autonomous vehicles hit the streets, they navigate with the help of avalanche photodiodes, or APDs. These semiconductor photodetectors capture returning laser pulses as part of lidar systems, and this APD-derived data determines the distance to other vehicles, to objects, and to people — information critical for safe driving.

Lidar is a fast-growing APD application, and, according to Anand Pandy, applications engineering leader at Excelitas Technologies Corp. of Waltham, Mass., cost considerations and the performance demands of lidar will lead to changes in avalanche photodiodes. "We see the trend moving from single-element APDs to arrays," he said.

MarketRReports projects the APD market will grow at a 3.7% compound annual rate over the next five years,[1] thanks to lidar and other imaging and detection applications. These applications could benefit from wider and more varied spectral detection ranges, greater sensitivity, the advent of APD arrays, reductions in cost, and other improvements. So vendors are responding with innovations in materials and manufacturing.



## Materials innovations

An APD converts light into electrons, enabling fast and potentially highly sensitive photodetection. The avalanche part of the APD refers to a multiplication of internal photoelectrons through impact ionization.

"Through this internal gain mechanism, the APD multiplies the primary photocurrent by a factor M, or the APD gain," Pandy said. He added that the multiplication ranges from 100 to many times that, depending on the APD configuration.

But there is nothing to multiply without an initial photoelectron, which only appears if the material absorbs a photon and generates an electron. Since different semiconductors absorb over different spectral ranges, no single material works across all applications. Silicon APDs, for instance, are used from the UV starting at 120 nm and on up to the near-IR at about 1100 nm.

Advancements in APDs include the commercialization of two types of structures: planar and mesa-based, according to Oleksandr Goushcha, lead scientist for semiconductor devices at OSI Optoelectronics of Hawthorne, Calif. "This allows devices with low excess noise and avalanche gains of several hundred," he said.

In addition to silicon, many other materials can be used in APDs. The list includes germanium (Ge), gallium arsenide (GaAs), indium gallium arsenide (InGaAs), indium phosphide (InP), gallium nitride (GaN), aluminum gallium nitride (AlGaN), and silicon carbide (SiC). With these materials, absorption runs out to about 1600 nm. The stacking of photodetection materials can result in devices that offer a response from the UV to the shortwave IR.

In its product line, OSI Optoelectronics uses silicon APDs tuned for a peak responsivity that is application dependent and ranges from 600 to 900 nm. The company also has InGaAs APDs that work at 1550 nm, the middle of the shortwave-IR portion of the spectrum, and an important wavelength in optical communications.

One relatively recent innovation consists of several hundred to many thousands of APDs connected in such a way that the group acts as a photon counter. Known as a silicon photomultiplier, or SiPM, this configuration is particularly attractive in medicine and the life sciences.

"For SiPMs, molecular imaging is among the main applications driving the growth due to their immunity to magnetic fields, allowing the concurrent application of magnetic resonance tomography in a single system," said Hooman Shakouri, senior director for strategic marketing and business development at OSI Optoelectronics.

Excelitas Technologies

Autonomous vehicles, or self-driving cars, will use lidars to safely navigate. APDs are a critical part of the lidar technology that probes the car's environment.

### Meeting the needs of lidar

Lidar currently attracts the most attention from APD makers, however, and this is pushing the industry in new directions. Most lidar systems operate at a wavelength of 905 nm, according to Exelitas' Pandy, and use silicon-based photodetectors that cost less than those made of other materials.

But this trend may be changing to adapt to the performance needs of autonomous vehicles. A car that is traveling 60 mph (97 kph) covers 88 ft/s (27 m/s). A self-driving car needs time to spot an object, determine what it is, decide what action to take, and then take it. This process can translate into several seconds of time and hundreds of feet of detection distance. And some objects on the road are not highly reflective. Black tire fragments, for instance, will produce very little return signal, making them potential road hazards because they are harder to detect.

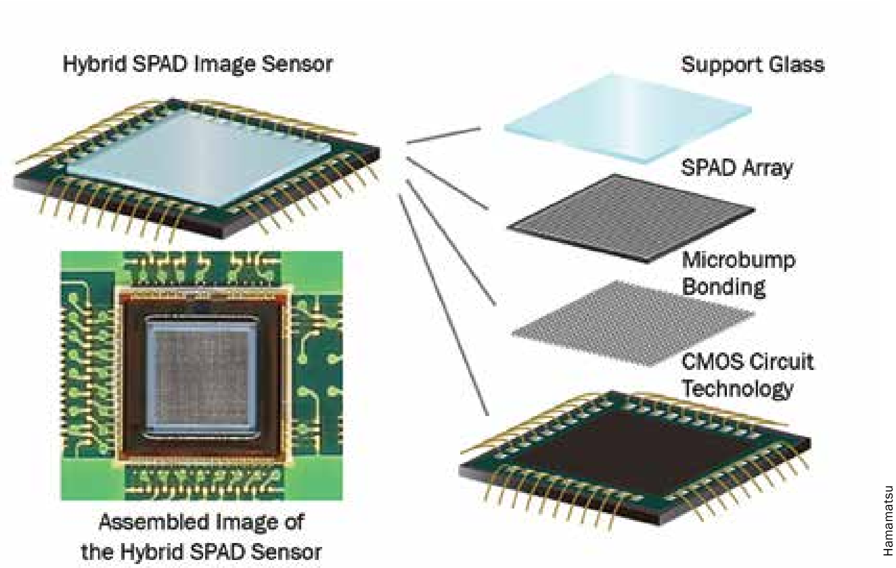
The goal for lidar is to reliably spot a dark object from a distance of more than 200 m, and to use a laser power low enough to avoid endangering vision. Pandy predicts such needs will push the industry to use APDs made of different materials than silicon, which is today's leading choice.

"Longer detection ranges of more than 200 m and eye safety are demanding longer wavelengths, such as 1550 nm," he said. "Hence, InGaAs APDs will be used in newer and more advanced lidars." Pandy added that both InGaAs and silicon APD-based lidars could be used at the same time in one system through fusion of sensor data.

Lidar application needs have spurred further innovations in APDs, according to Jake Li, business development manager for automotive lidar at Hamamatsu Corp. USA of Bridgewater, N.J. The company makes photodetectors using a wide variety of technologies and it manufactures both silicon and InGaAs APDs.

Li noted that one recent advancement is the single-photon avalanche diode, or SPAD. Like the related SiPM, it operates above the breakdown voltage, leading to an internal gain of up to 1 million, so one photon produces a multitude of electrons.

**Lidar currently attracts the most attention from APD makers, and this is pushing the industry in new directions.**




A SPAD sensor is a new type of APD that in some configurations can detect single photons. Its applications include lidar and spectroscopy.

Consequently, these devices can detect low-intensity signals, down to a single photon, with applications in lidar, spectroscopy, and the life sciences.

Lidar systems in cars should be small, rugged, reliable, and inexpensive. They should also be low power and able to operate across a wide temperature range. One way to improve performance in many of these areas is to move from a mechanical sweep of a beam to an approach called flash lidar. Here, the source acts like a flash, illuminating a scene with a single shot. It works similar to a camera.

For flash lidar to work, the photodetector must, like a camera, also have an array of almost uniformly responsive pixels. The APD equivalent can be found in linear arrays, which are strings of photodetectors, and in 2D arrays, which consist of a rectangular arrangement of APDs. Hamamatsu, like others in the industry, is addressing the issues presented by arrays.

"We're working on lowering the variation chip to chip," Li said. "When we lower that, you can actually make 2D arrays. We're also looking at decreasing the gap and lowering the crosstalk that an APD array would typically have."

Greater uniformity in APD response means the array elements produce a more uniform photon response. This ensures that differences in return signals occur because of differences in the surroundings, rather than because of the photodetectors themselves. Such uniformity can be achieved by cherry-picking through a pile of APDs to find ones that closely match each other. But it is better and less expensive to accomplish this with fewer variations between devices.

The gap to which Li refers is the distance between photodetectors in the array. A gap in a flash lidar means part of a scene will contain no 3D information. This gap cannot vanish entirely because APDs must be connected to other electronics via wiring to work, but the gap should be kept as small as possible.

Li said Hamamatsu is also addressing the issue of crosstalk. When a photon strikes one photodetector, it generates electrons that then end up in nearby APDs. To the electronics, this looks like a phantom photon. In an ideal APD array, crosstalk would be zero.

## Looking forward

Li said Hamamatsu is constantly making improvements to address these issues, as well as others related to cost, reliability, and performance of APDs. He noted that every photodetector has associated off-chip electronics, such as amplifiers, lenses, and filters. So, part of the ongoing improvements involves getting the components as close to the detector as possible and even onto the chip. The benefits can be significant.

"The closer you bring the electronics to the detector, the better it is in eliminating the noise and also improving the speed of the detector and the whole system itself," Li said.

Lidar technology is also increasingly being adopted in security, automation, and robotics, according to Vince Forte, chief technology officer at Latham, N.Y.-based Marktech Optoelectronics. The company is considering the development of InGaAs APDs, which will have a sensitivity from 800 to 1700 nm. These devices will complement Marktech's silicon APDs, which work between 400 and 1100 nm.

Forte is another who sees an increasing level of integration of components and functions into photodetector chips. Looking forward, this development will help improve results in every application.

"In the near future, APD ASICs (application-specific integrated circuits) may become readily available, as reductions in costs and size continually result in the integration of various components into a single microchip," he said. "This will also increase APD speed and performance."

hank@hankhogan.com

## Reference

1. MarketRReports (Feb. 2019). Global APD Avalanche Photodiode Market Research 2019 by Manufacturers, Regions, Type and Application, Forecast to 2024.