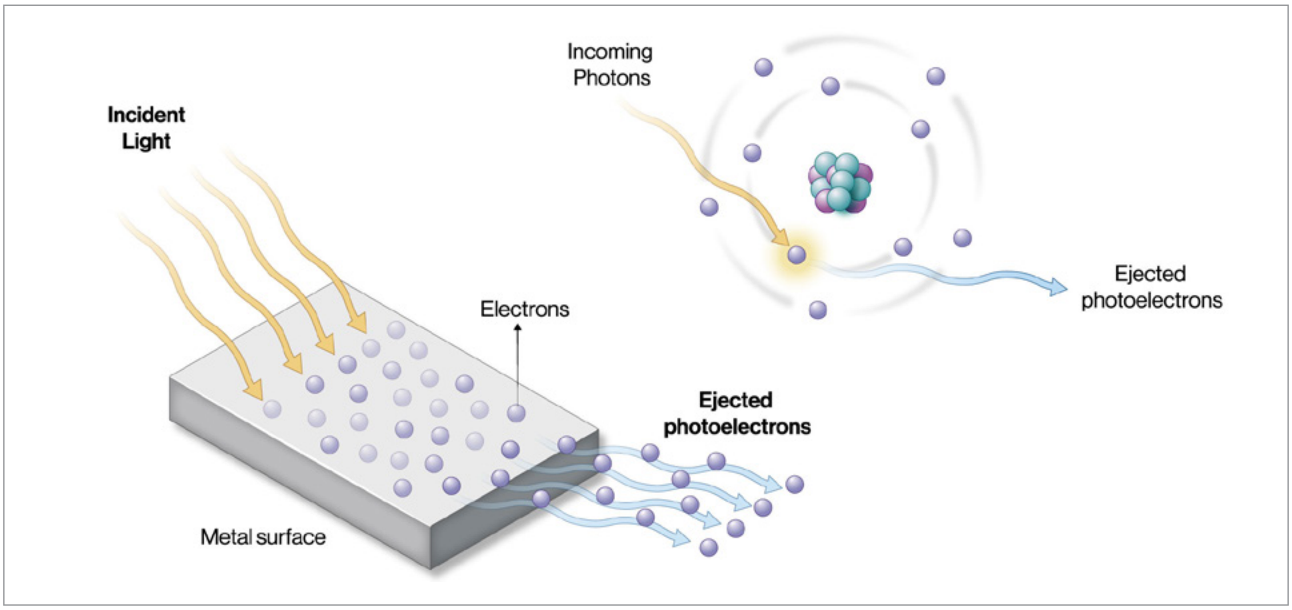
Harnessing Einstein's Photoelectric Effect: Advancements in LiDAR Technology and Its Impact on Modern Sensors

The legacy of Albert Einstein extends far beyond his renowned theory of relativity and the iconic equation $E=mc^2$. While many attribute his Nobel Prize in Physics to these contributions, the accolade was actually awarded for his groundbreaking explanation of the photoelectric effect. This seemingly minor discovery has vast implications in our everyday lives, influencing technologies we often take for granted, such as digital cameras and facial recognition systems found in smartphones and automation using LiDAR technology.

Understanding the Photoelectric Effect

Einstein's experiment demonstrated that light is composed of discrete energy packets known as photons. When light of a specific frequency strikes a metal surface, it liberates electrons, providing compelling evidence for the particle nature of light. The ramifications of this discovery are profound, particularly in how we harness the photoelectric effect in modern technology.



LiDAR and TOF: Applications in Automation

The most visible applications of the photoelectric effect are in digital image acquisition systems like digital cameras and facial recognition technologies. These systems rely on the principles of light emission and detection that are rooted in Einstein's findings. They significantly enhance our ability to capture and interpret visual data in real-time, making them integral to contemporary smartphone functionalities.

The photoelectric effect also plays a crucial role in detecting people and objects at various distances, enabling automation features like touchless doors and obstacle avoidance in robotics. These applications are based on the use of LiDAR (Light Detection and Ranging) technology and more specifically through the use of the Time-of-Flight (ToF) method.

LiDAR Technology: A Detailed Overview

The fundamental principle of TOF LiDAR is simple: a light source emits a concentrated beam of light that is reflected by an obstacle, such as a pedestrian or a car and bounces back to a photosensor. The sensor calculates the object's distance, based on the time the reflected light takes to reach it. This is shown in Figure 1.

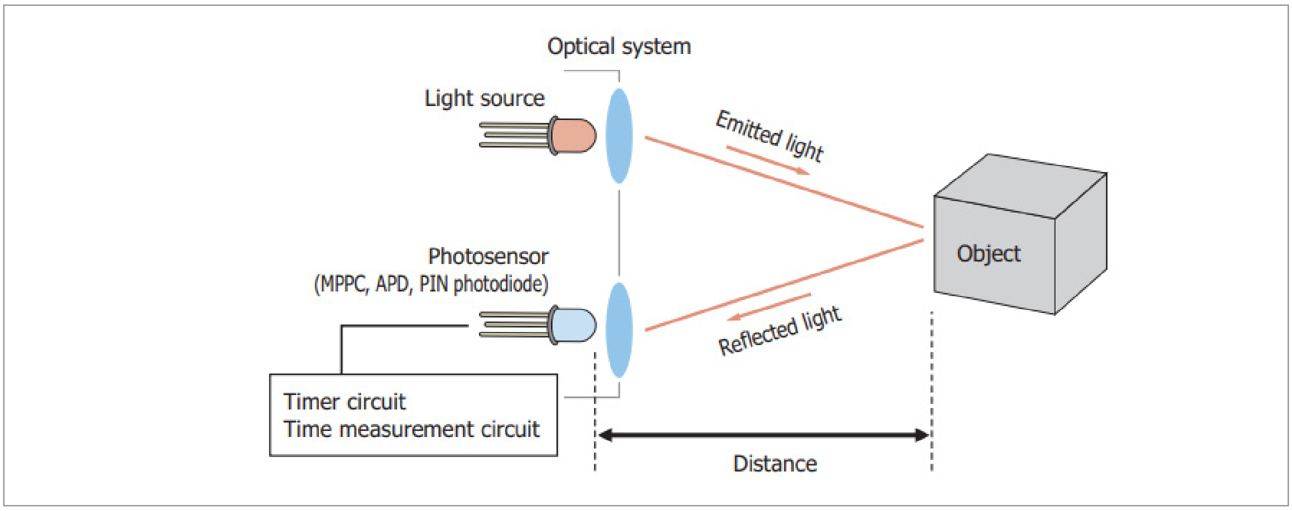


Figure 1: Basic principle of TOF LiDAR

Light Sources in LiDAR Systems

Various light sources can be employed in LiDAR systems, with the Pulse-Laser-Diode (PLD) being particularly effective due to its high peak power under pulsed operation. When selecting the best light source for your application, power is not the only parameter to consider. Factors such as electrical-to-optical conversion efficiency and the near-field pattern (NFP) are key. For instance, Hamamatsu Photonics offers PLDs with high efficiency and uniform light intensity (without temperature dependence), essential for accurate distance measurements.

We offer a range of PLDs with different peak output power and emission widths. These light sources can be used for distance measurements, such as laser radar and hazard monitoring in security applications.

In addition to standard products, various dedicated products can be provided, including PLDs with vertical emission and PLDs with an integrated driver (including FET driver and capacitors), referred to as micro-High Speed Pulse Laser modules (µ-HPL).

The Heart of LiDAR Technology: Photosensors

A photosensor is a device that converts light into an electrical signal based on the photoelectric effect. There are various types, and each will have its specific characteristics to fit the required need, based on measurement accuracy and distance.

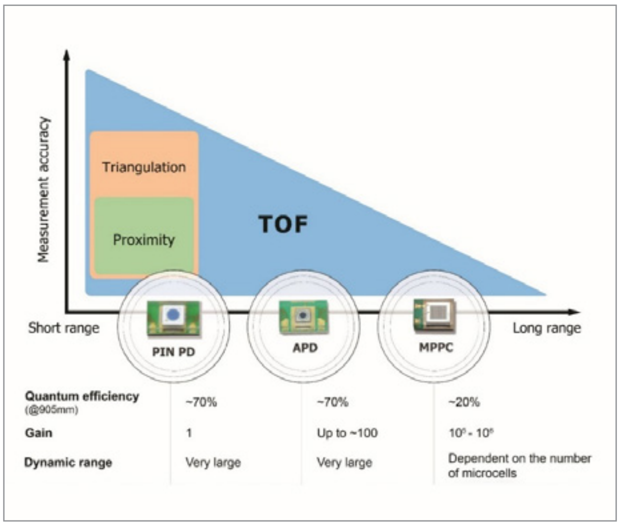
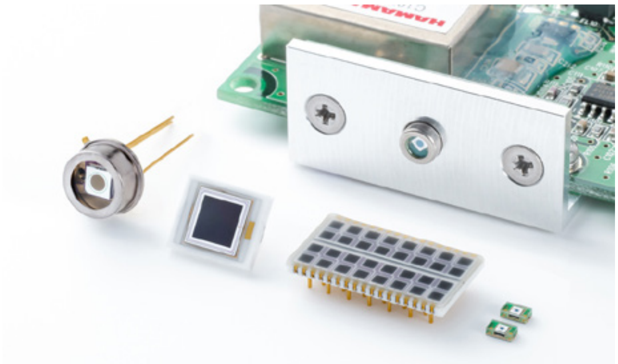
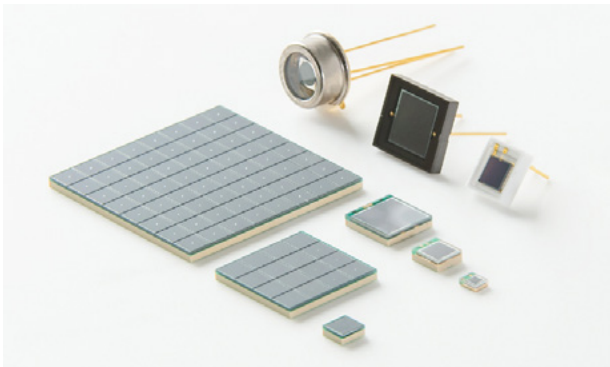


Figure 2: Types of detectors for TOF requirements

Silicon PIN Photodiode (PIN PD)
The most common and simple photosensor with high quantum efficiency and without any amplification, it is ideal for short-range detection due to its lack of gain.



Silicon Avalanche Photodiodes (APD)
When extending the detection range, a sensor with higher gain such as the Si Avalanche photodiodes (APD) is essential. It enables detection in low-light conditions and increases the speed of detection.



Multi-Pixel Photon Counters® (MPPC®)
Also known as *Silicon Photon Multipliers (SiPMs)* or *SPADs (Single Photon Avalanche Diodes)*, these devices are used in applications requiring the detection of single photons with a high gain or in very low light levels, while minimizing noise.

How do SPADs Work?

When we apply a reverse bias voltage higher than the APD's breakdown voltage, technically known as operating the APD in a breakdown state, we are in Geiger-mode operation. As illustrated in Figure 3, in this state, we reach a very high gain.

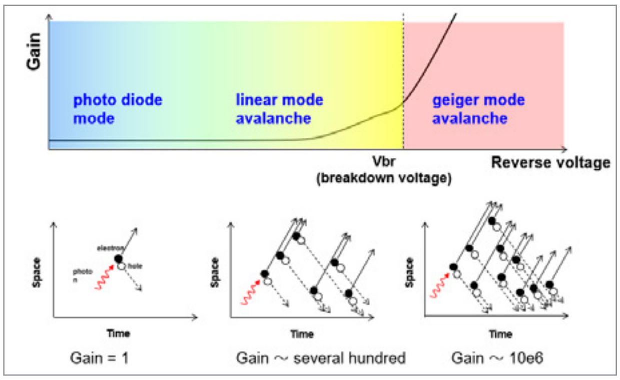


Figure 3: SPAD's Geiger-mode operation

To allow for the detection of a second incident photon, a quenching resistor must be added to suppress the current. This prevents surges from the depletion region once sufficient gain and adequate output signal amplitude have been attained. When multiple SPAD channels are collected into a single output, the result is an MPPC.

In instances where many pixels fire simultaneously, the output becomes the cumulative sum of the standard pulses. In scenarios where several photons are incident on the same pixel simultaneously, the signal manifests a 1 p.e. pulse as depicted in Figure 4.

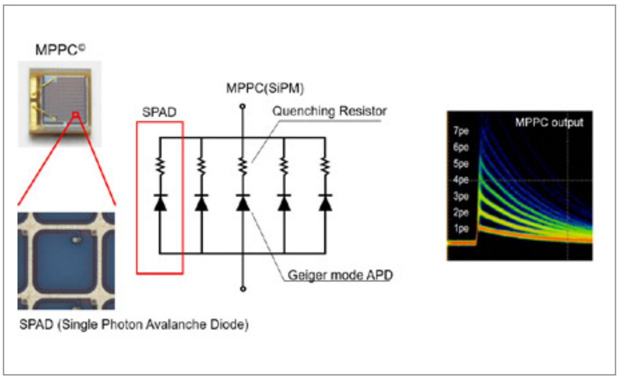


Figure 4: Unique MPPC structure and output

Hamamatsu's Si Avalanche Photodiode series S15415.

Leading the Way in Photosensors for LiDAR

Hamamatsu Photonics has been instrumental in developing solutions for LiDAR in the automotive industry, offering a rich portfolio of emitters and detectors for industrial and automotive LiDAR applications, including both APD and SiPM.

One example is the distinctive Gain Stabilized Silicon Avalanche Photodiode (Si APD). The Si Avalanche Photodiode series S15415 features a built-in temperature compensation function within the chip. This ensures a constant gain without requiring temperature adjustments or a temperature-driven circuit.

Hamamatsu has developed a new SIPM specifically for Industrial applications. The main advantage of this product is its ability to operate with a very low breakdown voltage (25V, total operating voltage below 50V). The high number of SPAD channels also enables it to function well in higher ambient light conditions.

Drawing on the remarkable evolution of the photoelectric effect from scientific curiosity to technological cornerstone, the ongoing development of APD and SiPM technologies not only advances LiDAR-driven automation and safety but also paves the way toward a future where intelligent systems, powered by these advancements, integrate effortlessly into our daily lives.

Contact our team of experts at info@hamamatsu.eu
to discuss your industrial LiDAR needs today.