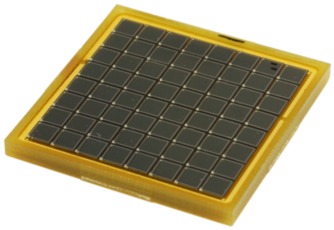


White Paper

Zecotek MAPD
(Multi-pixel Avalanche Photo Diode)

"Enabling the future of imaging and detection"

Zecotek Photonics Inc. (TSX-V: ZMS; Frankfurt: W1I) **www.zecotek.com** is a Canadian photonics technology company developing high-performance crystals, photo detectors, lasers, optical imaging and 3D display technologies for commercial applications in the medical diagnostics and high-tech industries. Founded in 2004, the company has three distinct operating divisions: imaging, lasers, and 3D display systems with labs and production facilities located in Canada, Singapore, Malaysia, and Russia. Zecotek commercializes its novel, patented and patent-pending technologies both directly and through strategic alliances and joint ventures with multinational OEMs, distributors and other industry leaders.

In 2009, Zecotek was honored with the prestigious Frost and Sullivan award for 'Best Enabling Technology' for its MAPD (Multi-pixel Avalanche Photo Diode) and LFS (Lutetium Fine Silicate) scintillation materials. The Company has featured on Discovery Channel's Daily Planet, and in 2010 was cited as one of the top ten Canadian technology companies to be the next 'big thing' for its 3D display system.

MAPD (Multi-pixel Avalanche Photo Diode)

Zecotek's Multi-pixel Avalanche Photo-Diodes (MAPD) are advanced high-performance solid-state photo detectors for the registering of various light intensities within the wavelength range from UV to near IR. The MAPD is designed to replace the earlier photo-detection technologies now used in areas such as HEP (High Energy Physics), astronomy, medical diagnostics, pharmaceutical research, and other areas of industry, security, and defense. In particular, the MAPD offers a more robust, sensitive, and cost effective replacement for the Photo Multiplying Tube (photomultiplier or PMT) in PET (Positron Emission Tomography – see below) medical imaging than earlier versions of SiPM and APD devices [see below].

Replacing the Photo Multiplying Tube (PMT)

PMT's belong to a class of vacuum tube devices based on the external photoelectric effect. Over the course of their development, PMT's have evolved into extremely sensitive detectors of light covering a broad spectral range from ultraviolet to the near-infrared wavelengths. This is achieved by amplification of the electric current generated by incident light by up to several million times, thus allowing detection of even individual photons at fairly high frequencies.

These parameters, along with their low noise and large active area have established PMT's as fundamental components in medical imaging, particularly PET scanning, bio-medical measurements, high-energy physics, astronomy, high-performance image scanning, as well as many other industrial applications.

Semiconductor devices, particularly certain types of avalanche photodiodes, can be used as alternatives to photomultipliers. The original devices dubbed the SiPM (Silicon Photo Multiplier) or MPPC (Multi-Pixel Photon Counter) were notably invented and patented by scientists who are now part of Zecotek. This breakthrough technology has since been integrated by various companies, including well-established semiconductor manufacturers and the world's largest suppliers of PMT's who produce devices based on an SiPM or MPPC design.

Replacing the Traditional Avalanche Photo Diode (APD)

The conventional Avalanche Photo-Diode (APD) is a semiconductor photo-detector working on the same principle of internal photo-effect as normal photo-diodes. However, unlike photo-diodes, it also includes an internal amplification stage, at the functional level similar to that of photo-multiplying tubes. This amplification is achieved through application of high reverse bias voltages (typically 100–200 V for silicon), which gives rise to the impact ionization effect also known as electron avalanche. APD's have been for many decades an industry standard in application areas where high-frequency (1MHz and more) incoming photo signals have to be detected. They provide modest signal gains (~50–200), limited because of very high sensitivity of this APD design to various non-uniformities of crystal lattice.

The technology powering Zecotek's MAPD has a strong potential in the domain of photo-detectors working in the linear mode (as do conventional APD's), and replacement devices developed on the basis of this technology will considerably improve on critical parameters such as gain, excess noise factor, radiation hardness, and production cost.

Zecotek's novel approach to APD design is based upon epitaxial structures grown on silicon substrate with deeply buried isolated avalanche channels. The first experimental samples of the new 3×3-mm^2 APD demonstrate gain of about 500 at working voltage of 130 V.

MAPD Technical Highlights

Building on the extensive experience acquired in the invention of the original SiPM technology and subsequent manufacturing of various SiPM devices, the Zecotek team have since considerably advanced the state of the art by introducing and patenting a new class of multi-element avalanche devices (MAPD's), whose capabilities by far surpass those of traditional SiPM detectors.

This patented technology is now the foundation of a new generation of Zecotek's MAPD devices, which allow both manufacturing of large-area detectors and, crucially, enable very high pixel densities.

The MAPD is based on a semiconductor structure deposited on a common silicon substrate with separate buried sensitive areas. This provides for 'avalanche' conditions (similar in principle to a PMT) which, together with a novel mechanism of re-setting each sensitive area after being triggered by an incident photon, delivers unsurpassed linearity and dynamic range while maintaining a highly competitive level in other parameters.

This competes favorably against surface-pixel devices, such as the SiPM or MPPC, which have the inherent limitation that as the number of pixels across a unit surface is increased, the critical parameter, PDE (Photon

Detection Efficiency) is reduced. This occurs because any surface-pixel device requires a certain level of dead (insensitive) space around the active pixel. This dead space cannot be easily scaled down as the pixel area is reduced, thus posing a limit on PDE values. So, for example, even at the density of about 2,000 pixel/mm^2, a posted manufacturing target for MPPC's, does not allow them to exceed 15% PDE. This in turn limits the utility of MPPC's in high-resolution PET applications [see below] that require a considerably higher PDE together with high pixel density.

Zecotek's MAPD's have no such limitation and, for most applications including importantly PET, provide a balance between numbers of pixels and the PDE. Zecotek's MAPD's feature sufficient PDE (25–30%) at pixel densities that are unachievable in conventional SiPM or MPPC devices. For example, in high-energy physics, such as calorimeters which deal with over 50,000 photons per pulse, Zecotek's MAPD's retain fully linear response, while surface-pixel SiPM or MPPC detectors would be heavily saturated.

Zecotek's MAPD has been produced in several configurations for both market entry and testing by end users. While the devices already produced and tested have been widely acclaimed as the next generation of photo-detection, the basic MAPD design offers a large area of potential for improvements in performance and variation in design and application.

Tests and applications to date have been undertaken by a number of high-profile, world-class institutions and end users, including:

- CERN, the European Organization for Nuclear Research, has been testing Zecotek's third-generation Micro-pixel Avalanche Photo Diode (MAPD-3N) for use in high-precision calorimeters in the framework of its NA-61 experiments. NA61 is being conducted at the Super Proton Synchrotron, which studies the final states produced in interactions of various beam particles with a variety of fixed nuclear targets at extremely high energies. Until the commencement of LHC programme, NA61/SHINE was the second largest experiment at CERN. The goal of this experiment is to measure the production of hadrons (a class of subatomic particles) in heavy ion collisions and to search for the critical point of strongly interacting matter. A new measuring device, named the Projectile Spectator Detector (PSD) calorimeter, will be used to measure the number of the non-interacting particles in the collisions, on an event-by-event basis. This allows experimenters to determine the number of particles participating in the reaction. The performance of the PSD is made possible through the Zecotek MAPD-3N's unique high pixel density of 15,000/mm^2 which provides the linear response and energy resolution, amongst other characteristics, required for these ultra sensitive experiments.

- At the University of Geneva, Switzerland, the MAPD photo-detectors have been selected as an alternative to photo-multiplier tubes (PMTs) in the development of new calorimeters for high-energy physics. This follows a recent order from the Swiss Institute of High Energy where Zecotek's MAPD photo-detectors will form a critical component in a new, high-performance hadron calorimeter, a device used in key experiments at the European Centre for High Energy Particle Physics (CERN) in Switzerland.

Recent technical symposia have underlined the merits of the MAPD and have directly resulted in enquiries for trail shipments for testing purposes from a number of leading researchers and institutions, in particular those focusing on PET (Positron Emission Tomography) imaging and HEP (High-Energy Physics). Zecotek is following these closely, and anticipates the results will be made publically available in upcoming international fora.

PET (Positron Emission Tomography)

PET is a widely used medical imaging technology in which a biological activity within the body is detected by the introduction of radionuclides linked to metabolic materials, such as sugars. In the process of metabolism, the radionuclides decay and release positrons. These recombine with electrons in the vicinity of the decay event, producing gamma rays, which are then converted into visible photons using a scintillating material (such as Zecotek's LFS). These photons are then registered and converted to an electronic signal by a photo detector. The resulting signals are then used to produce a computer-generated image. This technology is important in treatment of neurological and cardiac diseases as well as in cancer research, particularly in the detection of tumors, which by having higher metabolic rates than surrounding cell tissue, are thereby more easily detected.

While the PMT has been used for many years in PET scanners (and represents nearly one third of the cost of a PET machine), to obtain higher-performance data, especially related to geometric resolution, more sensitive and more compact devices are now required. A considerable improvement of the PET scanner performance can be achieved by increasing the number of photosensitive pixels per square millimeter and hence, linearity, as well as by boosting PDE (Photon Detection Efficiency) in the photo detectors themselves. (Another improvement is through the use of faster and brighter scintillation materials and where Zecotek's LFS also holds a lead.)

In addition to the requirement of better PET performance, there is a preference to relate PET scans, which essentially display metabolic data, with scans which can position this data within specific organs, such as produced by CT or MRI. MRI (Magnetic Resonance Imaging) offers a greater accuracy (granularity) in comparison to CT and, with the absence of CT radiation exposure, a PET/MRI solution is seen as a preferred combination. However, the disadvantage of PMT-based PET scanners is the susceptibility of the vacuum tube based PMT to the strong magnetic fields of the MRI.

Given the limitations of PMT's, and the inherent advantages of solid-state photo detectors, manufactures of PET systems are now attempting to move to silicon based solid-state analogues. Not surprisingly, companies who have been major suppliers of PMT's for PET machines are attempting to introduce solid-state replacement products marketed under the names SiPM or MPPC. However, as noted above, these devices are based on an obsolete patent and have inherent limitations in PET applications.

Integrated Detector Module (IDM)

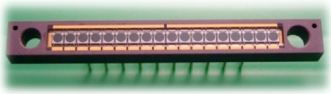
In addition to the testing and application of MAPDS in a variety of configurations and arrays, Zecotek has developed an Integrated Detector Module (IDM) configuration, which marries Zecotek's patented LFS scintillation material with an array of MAPD's in a patented 'plug and play' replacement for the PMT and crystal sets currently used in PMT's. The IDM also uses a patented Zecotek configuration, important for the high-resolution positioning of a diseased tissue. This detector configuration is known as DOI (Depth Of Interaction). Zecotek has also jointly developed with the University of Washington, Seattle, a rich portfolio of PET software and hardware solutions based on Zecotek's MAPD, LFS, and IDM technologies. ***This package of***

technologies provides the complete foundation for a new low-cost, high-performance generation of detectors for PET scanners.

In addition to providing a technology and approach suitable for PET inserts in MRI, the Zecotek approach also provides for devices with specialized imaging modalities and clinical applications in ENT, mammography, neurology, urology, as well as pharmacology research (small animal PET).

Future developments

The on-going R&D programme carried by Zecotek in the area of photo-detection aims at the realization of the great potential offered by its MAPD technologies. A key focus is to provide an MAPD replacement for any application currently requiring PMT devices with the potential for dramatic cost reductions (especially in mobile applications) as well as significantly broadening the MAPD market.



Zecotek MAPD: Experimental Performance Data

A number of different device types have been developed at Zecotek that cover a range of parameters and other ones specifically targeting PET and high-energy physics markets are under development. The table below summarizes main parameters of MAPD detectors. Zecotek's MAPD technology is inherently flexible and allows tailoring the main parameters of our devices to fit particular requirements of the customer's application. In particular, unmatched latitude of pixel density and dynamic range is available, and more different device types are being added to the MAPD family.

Parameter	Unit	Device type		
		MAPD-3A	MAPD-3B	MAPD-3N
Sensitive area	mm^2	3×3	3×3	3×3
Pixel density	mm^{-2}	15,000	40,000	15,000
Operating voltage	V	65–70	67–72	86–92
Gain		60,000	30,000	10^5
PDE	%	20	15	30
Dark current	nA	< 100	< 50	< 50
Dark count ($1pe^-$)	Hz/mm^2	$\sim10^6$	$\sim10^6$	10^5–10^6
Rise time	ns	3–10	3–10	2–5
Fall time	ns	80–100	80–100	60–80
Duration (FWHM)	ns	25–45	25–45	30–40

The following figure demonstrates the results of a radiation hardness test performed on a variety of multi-pixel detectors devices by irradiation with protons at MG Hospital (Boston). Relative response to LED pulses vs. exposure to 212-MeV protons for different samples and manufacturers was used as a measure of performance.

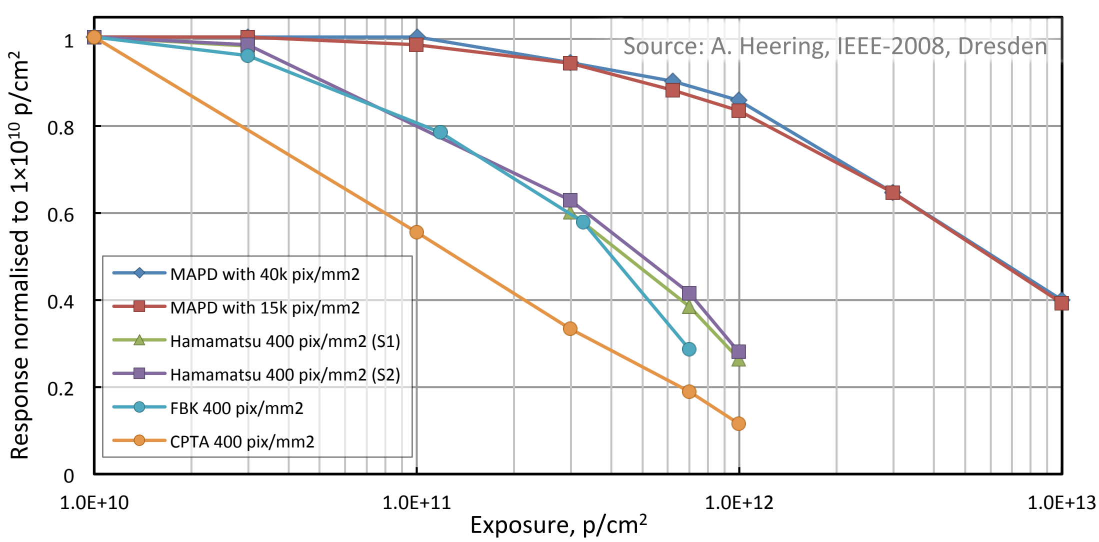


Fig. 1. Radiation hardness test of MAPD and other silicon detectors.

In real customer measurements, the MAPD-3 demonstrates good (22–32%) PDE in the range of 400–600 nm at a uniquely high pixel density of 15,000 mm^{-2} (see Fig. 2).

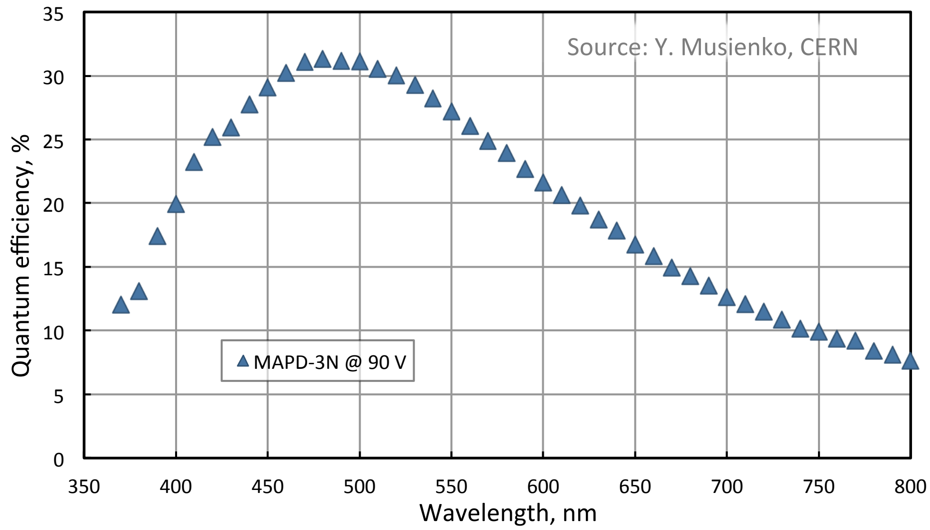


Fig. 2. Measured quantum efficiency of MAPD devices.

Very high linearity of Zecotek's photo-detectors has been repeatedly proven in experiments. As an example, the following drawing demonstrates that the MAPD-3N (135 000 cells, 3x3 mm^2) is a linear device up to 70,000 photons/pulse by plotting the dependence of the MAPD output signal in relative units on a number of incident photons.

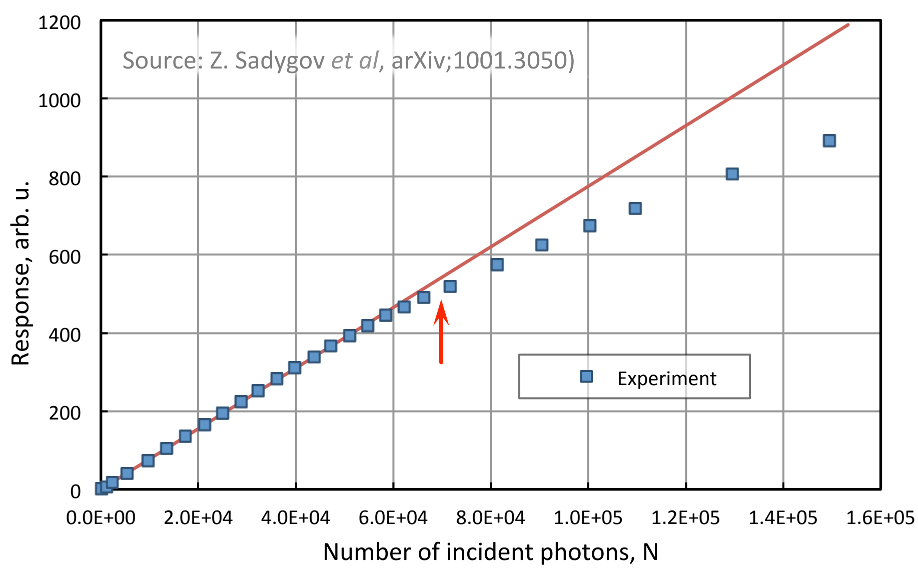


Fig. 3. Experimentally measured linearity of MAPD detectors.

Experimental studies that compare detector designs on the basis of MAPD and those on the basis of PMT have demonstrated that the achieved energy resolution of MAPD-based systems is as good or better than the performance of traditional PMT-based detectors. The following figure demonstrates one of such experiments measuring the responses of detectors composed of LFS crystals coupled to PMT and to MAPD to the reference ^{137}Cs signal.

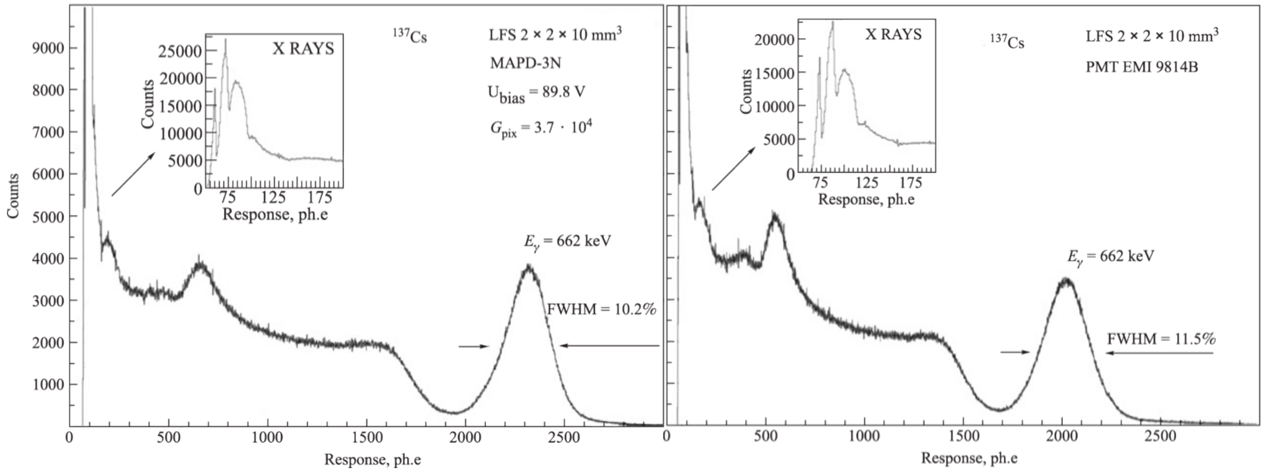


Fig. 4. Energy resolution comparison between MAPD and PMT used to detect gamma signal from ^{137}Cs isotope.

Several experimental studies of coincidence timing resolution have hitherto been conducted, which confirm high performance of MAPD detectors. This allows implementation of TOF methods for considerable improvement of contrast in restored PET images. Below, the results of time resolution measurements performed with a ^{22}Na source of gamma radiation are presented for MAPD-3N detectors used in combination with Zecotek LFS scintillation material.

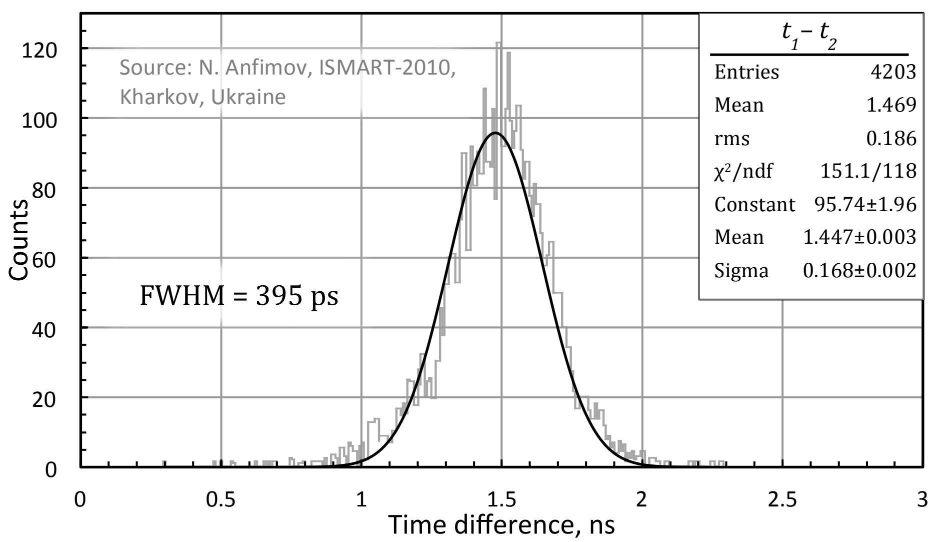


Fig. 5. Coincidence timing resolution of 395 ps is measured with MAPD detectors.