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Recent Development of MPPC at Hamamatsu for Photon Counting Applications

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The Multi-Pixel Photon Counter (MPPC) is one of the devices called SiPM (silicon photomultiplier). Many MPPCs have been used for positron emission tomography (PET) and high energy physics experiments, but to further improve the performance of these applications, new MPPCs are required. We developed new MPPCs designed for time-of-flight PET (TOF-PET) that have high photon detection efficiency (PDE) for the scintillation light used in this application, as well as good timing resolution. We incorporated these detectors into MPPC modules for TOF-PET, resulting in excellent coincidence resolving time (CRT). We also developed new MPPCs suitable for high energy physics experiments, such as Cherenkov telescopes. These new MPPCs have high PDE for the Cherenkov light generated by high energy cosmic rays and gamma rays, and the detectors' optical crosstalk was drastically reduced by removing the resin coating. In addition to developing these application-specific MPPCs, we also decreased the size of an MPPC's microcells because small microcells are required to detect more photons. We reduced the microcell's cell pitch down to 10μm and 15μm and added trenches to suppress crosstalk and dark counts. These new MPPCs have improved linearity and almost the same fill factor as trench-less conventional models that have a small cell size.

KEYWORDS: MPPC, SiPM, PET, Cherenkov telescope

1. Introduction

The Multi-Pixel Photon Counter (MPPC) is one of the devices called SiPM (silicon photomultiplier). The current generation of Hamamatsu's MPPCs with low afterpulse and low crosstalk were developed for various applications. The S13360 series with their high photon detection efficiency (PDE) for UV to visible light, low crosstalk, and low dark current have been useful for many precision measurement applications. The S14420 series have high PDE for visible to near-infrared light, making them suitable for fluorescence and biology-related measurements. The S13720 series, designed for light detection and ranging (LiDAR), detect near-infrared light with high sensitivity at 905 nm. Fig. 1 shows the PDE characteristics of our lineup of conventional MPPCs.

However, other applications for SiPMs such as TOF-PET, Cherenkov telescopes, and electromagnetic calorimeters have different requirements, so new developments in MPPC technology were needed to match the requirements and challenges of each application.

Positron emission tomography (PET) requires high sensitivity matched for Lutetium scintillators used, excellent coincidence resolving time (CRT), and a package suitable for coupling to scintillators. CRT translates to position uncertainty in TOF-PET, so it is a parameter that directly affects the performance of a TOF-PET scanner. High sensitivity contributes to good energy resolution, which provides a way to distinguish Compton scattering, as well as improving image reconstruction.

Cherenkov telescopes need high UV sensitivity to detect Cherenkov photons, which peak around 350nm. Optical crosstalk of background light can cause false triggers, so achieving high PDE with low crosstalk is advantageous. Detector improvements were needed to further reduce crosstalk probability.

Wide dynamic range is needed for applications such as electromagnetic calorimeters. The linearity of MPPCs can be increased by decreasing the size of the microcell to increase microcell density. However, the quenching resistance and crosstalk/dark count suppressing optical trenches reduce the fill factor and sensitivity of small microcells. The challenge is to integrate optical trenches in a small microcell size without compromising the sensitivity.

We developed new MPPCs to meet the requirements and challenges of PET and high energy physics experiments.

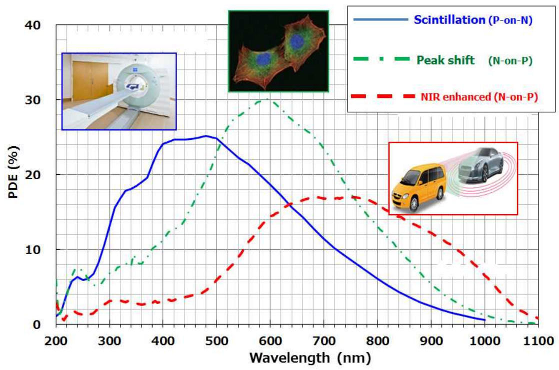

Fig. 1. The PDE characteristics of conventional MPPC product lines whose cell pitch is 25μm.

2. Development of MPPCs

2.1 MPPCs for PET

Detectors for PET must have high sensitivity and a suitable package for coupling to scintillators. The new S14160 series (single channel) and S14161 series (multi-channel arrays) with 50μm cell pitch are designed for time-of-flight (TOF) PET. These MPPCs have high PDE for scintillators' emission light (Fig. 2) and a breakdown voltage of about 37V, which is lower than older MPPCs. They also have a tileable package, which makes it easy to form active areas with very small gaps between each device.

The coincidence resolving time (CRT) is one of the parameters that improve the performance of TOF-PET. [2] The measured CRT FWHM of the S14160/S14161 series with 50μm cell pitch is about 200ps (Fig. 3). We incorporated the S14161 series (which have superior time resolution), Lutetium scintillators, an ASIC, and a power supply into MPPC modules for PET that get excellent CRT.

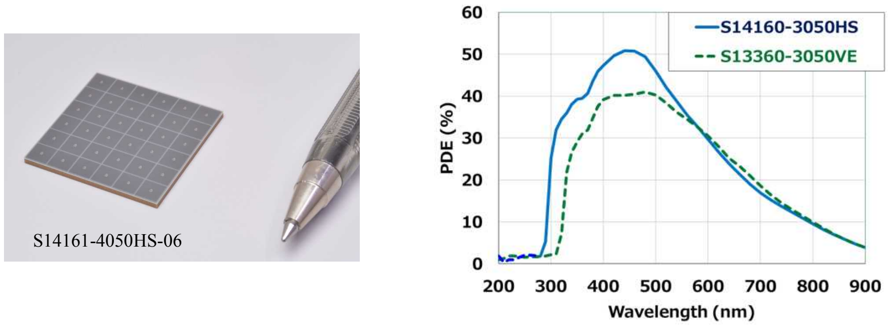

Fig. 2. Example of multi-channel MPPCs designed for PET (Left). These MPPCs have higher PDE for UV to visible light than older models (Right).

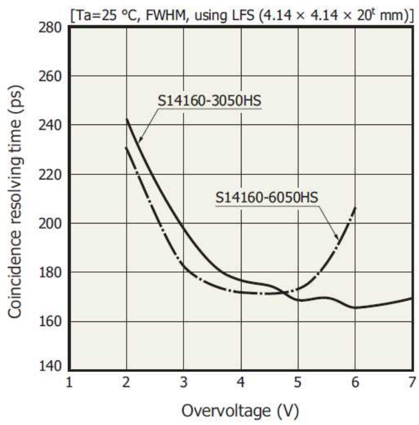

Fig. 3. CRT FWHM measurement data of the S14160 series. S14160-3050HS has a 3x3mm^2 active area and 50μm cell pitch. S14160-6050HS has a 6x6mm^2 active area and 50μm cell pitch.

2.2 MPPCs for Cherenkov telescopes

In many high energy physics experiments, researchers plan to use Cherenkov telescopes to detect Cherenkov light generated by high energy cosmic rays and gamma rays. Sensors to detect Cherenkov light must have high PDE for UV and low crosstalk probability. Designed for Cherenkov telescope experiments, the new MPPC S14520 series have high PDE for the UV region because they are coated with UV-transparent resin. Also, the overvoltage required to generate high PDE in the new models is lower than that for the older models, so it is possible to get high PDE and high gain with low dark counts and low crosstalk probability (Fig. 4). We investigated methods to further reduce crosstalk probability and found that fabricating the S14520 series without resin coating was successful. The devices without resin have higher PDE for the UV region and lower crosstalk probability than devices with resin coating (Fig. 5). We plan for the S14520 series to include products with resin coating and products without resin.

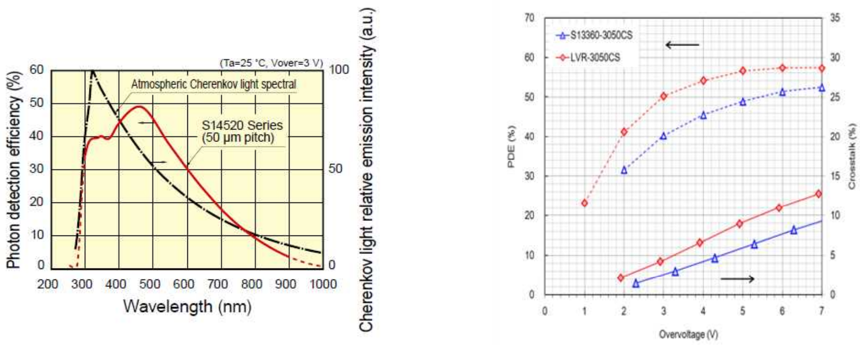

Fig. 4. The S14520 series have high PDE for the UV region (Left). The measurement results of the S14520 series are shown as LVR-3050CS. The S14520 series can get high PDE with low crosstalk probability (Right).

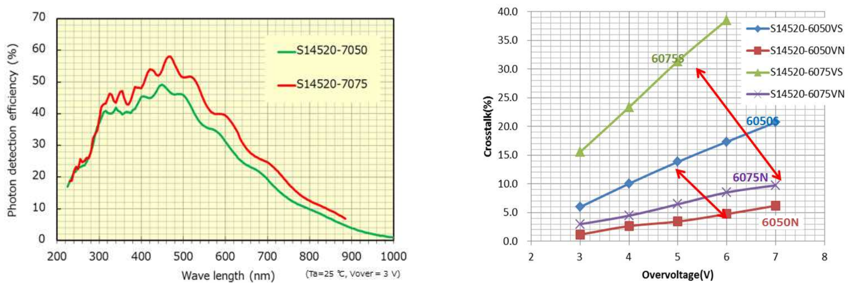

Fig. 5. The S14520 series without resin have high PDE for the UV region. The active area of these MPPCs is 7x7mm^2. The cell pitch of S14520-7050 is 50µm and S14520-7075 is 75µm (Left). The S14520 series without resin have much lower crosstalk probability than the MPPCs with resin coating. The products labeled with "S" at the end are MPPCs with resin coating, and those with "N" are MPPCs without resin (Right).

2.3 MPPCs with small microcells

Some detectors used for high energy physics experiments like electromagnetic calorimeters need high PDE and wide dynamic range. The PDE and the linearity of MPPCs depend on the microcell size. MPPCs that have small microcells can detect more photons, but both the active area's fill factor and the PDE decrease. To keep a large fill factor, conventional MPPCs, such as the S12571/S12572 series with 10µm and 15µm cell pitch, do not have optical trenches to suppress crosstalk probability and dark counts. The new MPPC S14160 series with 10µm and 15µm cell pitch are fabricated using a new fine-pitch wafer process developed for the MPPCs. These MPPCs have trenches but keep almost the same fill factor as the S12571/S12572 series. Fig. 6 shows images of the new microcell design with trenches. Table I shows the comparison of several MPPC designs. The S14160 series' PDE at lower overvoltage is improved by the new microcell design and tuning of the internal electric field (Fig. 7), and their crosstalk probability and dark count rate are suppressed by the trenches (Fig. 8). In addition, the linearity characteristics are improved by crosstalk suppression (Fig. 9).

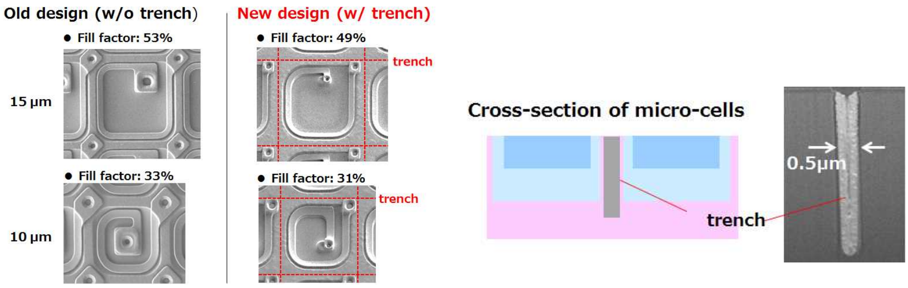

Fig. 6. Images of the microcell designs of the S12571/S12572 series and the new S14160 series (Left). The width of the trenches of the new S14160 series is 0.5μm (Right).

Table I. Characteristics comparison of various MPPC series

	S12571	S13360	S14160 (Latest)
Breakdown voltage	65 V	53 V	38 V
Trench isolation	none	Yes	Yes
Trench width	-	~ 1 μm	~ 0.5 μm
Fill factor	10μm: 33% 15μm: 53%	10/15μm no lineup	10μm: 31% 15μm: 49%

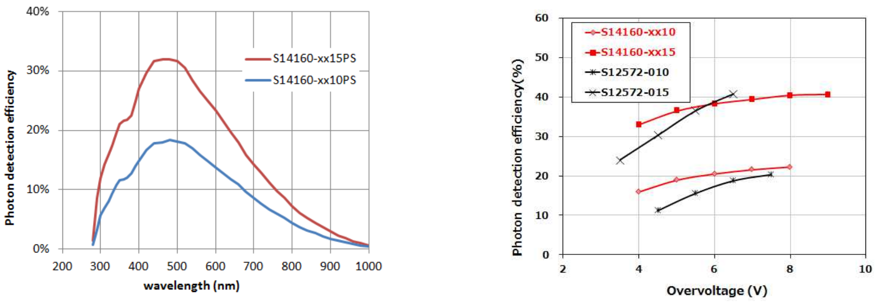

Fig. 7. S14160-xx15PS is a new MPPC with 15μm cell pitch and S14160-xx10PS has 10μm cell pitch. The new S14160 series have higher PDE at 450nm (Left). The new S14160 series with small microcells have higher PDE at lower overvoltage than the S12571/S12572 series (Right).

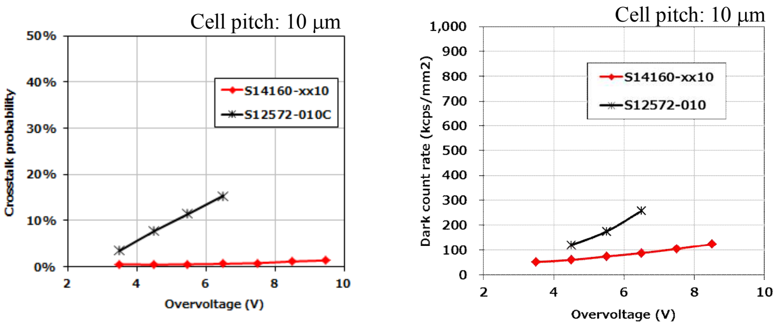

Fig. 8. The new S14160 series have low crosstalk probability (Left). Dark count rate is also suppressed by the trenches (Right).

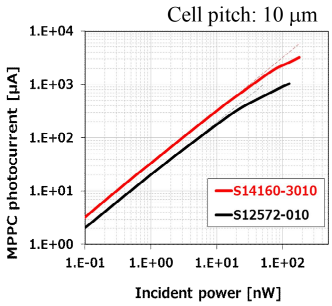

Fig. 9. The linearity characteristics of the S14160 series with 3x3mm^2 active area and 10µm cell pitch

3. Conclusion

Hamamatsu Photonics developed the new MPPC S14160/S14161 series with 50µm cell pitch. These detectors have 450nm peak wavelength and 50% PDE at 450nm. The measured CRT FWHM of these MPPCs is about 200ps, and modules comprised of these detectors and an ASIC have been developed to get excellent CRT.

The new S14520 series were designed for Cherenkov telescopes. They have high PDE for UV light, which is suitable for detecting Cherenkov light. The overvoltage required to get high PDE is lower than that for conventional models, so these MPPCs can efficiently detect Cherenkov light with low crosstalk and dark counts. One way to further reduce crosstalk probability is by removing the MPPC's resin coating. The S14520 series without resin has much lower crosstalk probability than the MPPCs with resin coating.

The new MPPC S14160 series, which have small microcells with trenches to suppress crosstalk probability, were developed. These MPPCs have high fill factor and PDE, and their linearity was also improved by suppressing crosstalk probability. To use these MPPCs as a detector for calorimeters in high energy physics experiments, it is necessary to evaluate their resistance against radiation.

References

[1] Terumasa Nagano et al., Development of new MPPC with higher NIR sensitivity and wider dynamic range, 2017 SPIE OPTO

[2] Terumasa Nagano et al., Timing resolution dependence on MPPC performance parameters, 2014 IEEE Nuclear Science Symposium and Medical Imaging Conference