New improvements to a specialized Multi-Pixel Photon Counter (MPPC) for neutrinoless double-beta decay and dark matter search experiments

K. Yamamoto 1, R. Yamada 1, K. Kobayashi 1, K. Sato 1, A. Ghassemi 2, 1 HAMAMATSU PHOTONICS K.K., 2 Hamamatsu Photonics USA

ABSTRACT

Hamamatsu Photonics K.K., a major manufacturer of a wide variety of silicon photodetectors including the Multi-Pixel Photon Counter (MPPC), has developed VUV-MPPCs that are capable of detecting light down to 120 nm, covering scintillation wavelengths of liquid xenon and argon with cryogenically compatible, ultralow-RI packaging options. We developed a 4th generation of VUV-MPPC (VUV4) for cryogenic physics experiments. In addition to diminished afterpulsing and inter-pixel crosstalk, we have achieved improvement of VUV photosensitivity in this new MPPC through new modifications of the device structure. By achieving these results and continuing our MPPC improvements, we hope to make a valuable contribution to the physics community’s efforts towards discovery of dark matter and the neutrinoless double-beta decay.

Introduction

Physics experiments using LXe or LAr scintillator

- Liquid xenon (LXe) and liquid argon (LAr) are used as scintillators for dark matter search or neutrinoless double-beta decay experiments. Their scintillation peak spectra are in the VUV region, and their temperatures are cryogenic.

VUV-sensitivity improvement

- VUV-MPPC contains a metal quenching resistor to maintain its pulse shape at low temperatures. The metal resistor has 1/5 the temperature coefficient of the poly-Si resistor, so its resistance has excellent stability against temperature changes.
- SPICE simulation confirmed that there is a clear difference in pulse shapes between the metal and poly-Si resistors at lower temperatures.
- VUV-MPPC with metal quenching resistor maintains its pulse shape at both room and low temperatures, but MPPC with poly-Si resistor has longer pulse tails and recharge time at low temperatures.

Our solution for direct detection is the “VUV-MPPC” series.

- For VUV light detection, precise control of MPPC’s protective layer and non-sensitive region is required.
- Electrons excited by VUV light are transported to the avalanche region by an electric field. To obtain higher carrier collection efficiency, a defect-less device is required because crystal defects cause recombination of electrons and holes.

VUV-sensitivity improvement

- VUV-MPPC has VUV-sensitivity down to 120 nm.
- The new 4th generation VUV-MPPC (VUV4) has improved photo detection efficiency, which is much higher than the 3rd generation VUV-MPPC (VUV3).
- Since optical crosstalk is still suppressed by the inter-pixel trench structure, VUV4-MPPC has improved signal-to-noise ratio.

Cryogenic temp. stability

- VUV-MPPC contains a metal quenching resistor to maintain its pulse shape at low temperatures. The metal resistor has 1/5 the temperature coefficient of the poly-Si resistor, so its resistance has excellent stability against temperature changes.
- SPICE simulation confirmed that there is a clear difference in pulse shapes between the metal and poly-Si resistors at lower temperatures.
- VUV-MPPC with metal quenching resistor maintains its pulse shape at both room and low temperatures, but MPPC with poly-Si resistor has longer pulse tails and recharge time at low temperatures.

Package technology for physics experiment with liquid scintillator

- For rare event search experiments that require a low-noise background, MPPC must have reduced radioisotope (RI) content in its constituent materials.
- We have measured the RI level of each package material candidate and developed the ultralow-RI MPPC.

Low temperature resistivity test

- Package reliability is one of the concerns for liquid scintillator applications.
- A thermal shock test was implemented for each Low-RI MPPC.

Results

- No damage in packages and chips
- Electrical characteristics did not change.

Conclusion

Overview of Hamamatsu’s product development for physics experiments using liquid scintillator

VUV-MPPC

- The 4th generation of VUV-MPPC (VUV4) has achieved a high signal-to-noise ratio, and its pulse shape is not affected by temperature.
- Ultralow-RI packaging

Cryogenically compatible, ultralow RI-level packages have been developed for direct and indirect detection of VUV scintillation light.

Communication & Collaboration

- We’d love to hear your thoughts regarding current product features along with your ideas for improvements.
- We’d also be interested in collaborating with well-equipped researchers on development of ultralow-RI packaging.
- Please feel free to contact us through your local Hamamatsu sales representative.