Abstract

This work undertakes a comprehensive characterization of Silicon PhotoMultipliers (SiPMs), with a particular emphasis on the Near Ultra Violet - High Density with Metal-filled Deep Trench Isolation (NUV-HD-MT) technology fabricated by Fondazione Bruno Kessler (FBK), focusing on its timing performance. From the fundamental principles governing SiPM operation to the detailed experimental characterization and analysis of the factors that ultimately limit time resolution, this research provides valuable insights, which will be useful for future technology developments. Owing to their exceptional characteristics, particularly their excellent time resolution, SiPMs have become highly relevant in fields such as large-scale physics experiments and medical imaging applications. A critical parameter defining SiPM timing performance is the Single Photon Time Resolution (SPTR), which measures the uncertainty in the time of arrival of a single photon impinging on the detector surface. SPTR is a key parameter affecting the Coincidence Time Resolution (CTR) of a Time-of-Flight Positron Emission Tomography (ToF-PET) scanner. Since SiPMs are core components in modern ToF-PET machines, optimizing their timing performance is crucial to enhance the performance of the entire system, to obtain better image quality and, ultimately, to improve the accuracy of cancer detection. The primary focus of this work is the analysis of the SPTR of (i) Single-Photon Avalanche Diodes (SPADs), which are the building block of SiPMs, with different sizes of their active area and (ii) of SiPMs with different active areas. The analysis was carried out by studying the different contributions to the SPTR, including the fundamental limits of the avalanche build-up statistics and of the time jitter due to the electronic noise. Furthermore, the performance improvement provided by a timing-optimized microcell layout, featuring a metal mask around each microcell, has been evaluated, along with its impact on time resolution. Finally, the CTR of a ToF-PET-like system has been measured in the laboratory, outlining the potential of this SiPM technology for real medical applications. The insights on timing performance achieved with this research will help the development and continuous optimization of FBK

SiPM technology, providing significant innovations for fast timing applications in medical imaging, with a relevant impact on society.