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Solid-state timing detectors enabling ion time-of-flight measurements

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This study reports on the performance of Avalanche Photodiode (APD) and Silicon PhotoMultipliers (SiPM) as a timing detector for ion Time-of-Flight (TOF) mass spectroscopy. The application of the silicon devices will eliminate the high-voltages and provide compact, robust, and rugged solutions compared to conventional Microchannel Plates (MCP) and Channel Electron Multipliers (CEM).

First, we found that the fast signal carrier speed in a reach-through type APD enables an extremely short timescale response with a mass or energy independent $<$2 ns rise time for $<$200 keV ions (1$-$40 AMU). The time resolution was determined by the thickness of the drift layer, rather than the polarity of the read-out signals. When combined with a MCP to detect start electron signals from an ultra-thin carbon foil, the APD comprises a novel TOF system that successfully operates with a $<$0.8 ns intrinsic timing resolution even using commercial off-the-shelf constant-fraction discriminators. Application of this method enables simultaneous timing and energy measurement to eliminate the stop MCP in the TOF system. Furthermore, the $\sim$ns short-window coincidence allows correlations of the MCP stop signals and APD stop signals, which can be used to configure the anti-coincidence logic to reject the background noise from penetrating radiation.

Second, thin dead-layer SiPMs are also tested for the capability to directly count particles to potentially replace the MCPs. Although the energy measurement will not be provided with this device, the timing resolution of SiPMs reaches $<$150 ps due to a thin depletion layer and a high gain ($\sim 10^6$). Electrons and protons with $>$1 keV energy were both countable using the device. The investigated proton detection efficiency ranged from 1% at 1 keV, and plateaued at the detector open area ratio (74%) above 5$-$6 keV. Considering the agreement between the simulation and measurement, the detection process was dominated by the ionization loss of incident particles in the sensitive volume in the pixel. Dark counts are the biggest issue in actual application, but can be mitigated effectively by applying multiple secondary electrons and double (or quadruple) anticoincidence noise rejection approaches based on the required noise levels.