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Study on Recovery Time of Silicon Photomultiplier with Epitaxial Quenching Resistors

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Silicon photomultiplier (SiPM), which consists of multiple pixels of avalanche photodiodes working in Geiger-mode (G-APD) is a promising semiconductor device in low level light detection for its excellent performances such as high response speed, low operated voltage, insensitive to magnetic field and small volume. The SiPM with epitaxial quenching resistors (EQR SiPM) using epitaxial silicon layer below p-n junction as the quenching resistor has been developed by the Novel Device Lab (NDL) at Beijing Normal University. EQR SiPM resolves a conflict between wide dynamic range and large photon detection efficiency (PDE), which exists in most commercial SiPMs for their poly-silicon quenching resistors on the surface. In some high energy physics and medical imaging, strict demands are put forward on the recovery time of SiPM that means device must be restored in short time after detecting a photon and prepare for the next photon as soon as possible, e.g. Compact Muon Solenoid (CMS) detector in Large Hadron Collider (LHC) and computerized tomographic scanning (CT). When upgrading the LHC for higher luminosities, the bunch spacing intervals is planned to be decreased to 12 ns, thus the dead time of detection is required shorter than the interval time. When detecting at the CT system, SiPM with shorten recovery time is welcome for scan time could be reduced. The time needed to recharge a pixel after a breakdown has been quenched due to the finite time taken to quench the avalanche then reset the diode voltage to its initial bias value is defined as recovery time (or dead time). It is important to measure the recovery time for studying the internal mechanism of SiPM and to design detectors. In this manuscript, the EQR SiPM produced by NDL has P on N structure and pixel size of 10μm. The recovery time is mainly investigated with double light pulse method, which employ two consecutive laser pulses with a defined relative time differences varying from several nanoseconds to hundreds of nanoseconds, and record the charge number change with the corresponding time, then fit out recovery curve to determine the recovery time. By illuminating whole sensor, the overall recovery time of all pixels was measured; by partially illuminating the detector using a bare optical fiber with diameter of tens of micrometer, the partial recovery time of fired pixels was obtained. The devices were all tested on optimized over-bias voltage and at room temperature. The results show that the recovery time of device has a great dependence on the active area of device and the number of fired pixels. The larger active area or the more fired pixels, the longer recovery time. For the EQR SiPM with active area of 1.4mm2, the overall recovery time was characterized as 15ns. For the EQR SiPM with active area of 3mm2, the overall recovery time was 30ns, and the partial recovery time was 6ns while the number of fired pixels were controlled about 2000. Though the SiPM has small pixel size and small RC time constant, the pixels can't possibly be fired synchronously when they are bias on, that lead to pulse-spreading thus broaden recovery time. In addition, the adding capacitance of pixels, the relative circuit and the distance of fired pixel to extraction electrode all affect characterization of the recovery time.

Primary author: Ms JIANG, Jiali (Novel Device Laboratory, Beijing Normal University)

Co-authors: Prof. HAN, Dejun (Novel Device Laboratory, Beijing Normal University); Mr JIA, Jianquan (Novel Device Laboratory, Beijing Normal University); Prof. LIANG, Kun (Novel Device Laboratory, Beijing Normal University); Prof. YANG, Ru (Novel Device Laboratory, Beijing Normal University); Dr ZHAO, Tianqi (Novel Device Laboratory, Beijing Normal University)

Presenter: Ms JIANG, Jiali (Novel Device Laboratory, Beijing Normal University)

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