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Development of P-on-N Type Silicon Photomultiplier with Epitaxial Quenching Resistors

Silicon photomultiplier (SiPM) is alternative to conventional PMT in various applications due to its high photon detection efficiency (PDE), excellent resolution for single photon detection, insensitivity to magnetic field, low operating voltage and convenience for integration, etc. SiPM with epitaxial quenching resistor (EQR SiPM) is one of the main SiPM technologies, which can effectively reduce the dead area including the polysilicon resistor generally located on the surface, further improve the dynamic range meanwhile consider the PDE.

In the Novel Device Lab (NDL) at Beijing Normal University, the research and development for EQR SiPM has always been focused on. In this report, the EQR SiPM using P-on-N silicon process is introduced for the first time. The P-on-N type EQR SiPM comprises thousands of APD units, which consist of N-enriched region forming high electric field between N-type epitaxial silicon wafer and P++ surface layer. The epitaxial region below the p-n junction functions as the quenching resistor. Thanks to electrons initiate the avalanche while traveling from top into the bulk, the P-on-N type SiPM could have high PDE about two times to the N-on-P type SiPM. Moreover, very thin P++ surface layer may benefit to absorb photon with short wavelength and generate electron transferring at N-type region to trigger avalanche, thus enhance the PDE for blue-violet light.

The P-on-N type EQR SiPM has active area of 3×3mm2 and pixel size of 10μm, that the fill factor equals to 40%. The device has optimized isolation region between APDs and the leakage current was measured about 10pA. The maximum over-bias voltage was 9V that means avalanche electricity being lead to the electrodes easily. At 293 degrees Kelvin and over-bias 6V, the dark count rate was 7MHz; the crosstalk rate was 4%; the after pulse rate was 13%. With the temperature decreasing, the dark count rate decreased obviously. The gain of SiPM was 2.1×105. By gradually increasing the light intensity, the dynamic range of the device was tested as 6×104. With double light pulse method, the overall recovery time of SiPM was determined to 30ns. Using random photon counting method, the PDE spectrum was obtained, which had 30% peak value at 420nm. Compared with formerly reported N-on-P device by NDL, the characteristics of P-on-N structure EQR SiPM, esp. PDE, have been significantly promoted (reference: "Feasibility Study on Silicon Photomultiplier with Epitaxial Quenching Resistors as the Readout for PET Detectors", IEEE TRANSACTIONS ON NUCLEAR SCIENCE, 63(1):17-21, FEBRUARY 2016).

In conclusion, the EQR SiPM fabricated by NDL using P-on-N silicon process exhibits better performance. The EQR SiPM is a potential solid-state photon counting sensor and is supposed to be applied in astrophysics, high energy physics and nuclear medicine imaging, etc.

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