Investigation of Random Telegraph Signal Fluctuations of Dark Count Rate in CMOS SPAD Stuctures

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CMOS technology for the realization of Single-Photon Avalanche Photodiodes (SPADs) is strongly growing interest for the big advantages in pixel circuitry integration for signal processing [1]. Timing resolution achievable by SPAD devices makes it very attractive in astronomic imaging applications for the observation of fast transient phenomena. In several fields where single-photon sensitivity and good timing resolution are required, detection based on SPAD is preferred [2].

In many applications, like vision camera or lidar implementation, SPAD devices are required to operate in a radiation environment. Radiation-induced defects in silicon structure, to which new energy levels in the bandgap are associated, can compromise SPAD performance, since they cause the generation of carriers in depletion regions through both thermal and tunnelling processes [3, 4, 5]. Other than the increase of DCR, the presence of the defects degrades the performance of SPAD devices inducing dark counts discrete fluctuations, known as Random Telegraph Signal (RTS) [6, 7].

In this paper we analyse the RTS phenomena of two different SPAD structures fabricated in a 150 nm CMOS process after the irradiation with protons. The test chip used contains two layouts: one structure based on P+/Nwell junction enclosed in a low-doped region in order to create a guard-ring to avoid premature edge breakdown; a second structure is constituted by Pwell/Niso junction. More junction details are described in [8-10].

The devices have been irradiated with protons by using a 14 MV Tandem accelerator and a Superconducting Cyclotron (SC) able to accelerate protons up to 62 MeV we irradiated the devices. Both irradiations have been performed at Laboratori Nazionali del Sud (LNS) - Istituto Nazionale di Fisica Nucleare (INFN) in Catania (Italy) (Fig. 1).

![Fig. 1: Left: the SPAD test beam setup at LNS Cyclotron; Right: observed four-level RTS in one SPAD pixel](image)

After the irradiation a large fraction of pixels in the devices show RTS behaviour and it was observed that SPAD architecture layout influences strongly the RTS occurrence probability. The switching behaviour of DCR levels suggests that, in many cases, the defect clusters induced by proton irradiation rearrange randomly its configuration.

In order to investigate deeply the RTS behaviour we measured in more detail RTS characteristics for a sub-sample of two-level RTS pixels for each of two structures (Fig. 2). In particular we studied the RTS occurrence as a function of the temperature in order to plot the RTS time constants vs. temperature and to extract the relative activation energy.

![Fig. 2: RTS two-level switching as function of the temperature for a given SPAD pixel](image)

The values obtained in this work for the time constant activation energy are in agreement with the calculated kinetics of the reorientation of the vacancy relative to phosphorous atom in a (P-V) center defect [11].

In order to try to distinguish P-V center and other defects to be responsible for RTS we performed a temperature isochronal annealing up to 250°C with a temperature step of 50°C.

We observed that the unannealed factor shows a smooth reduction behaviour for the RTS occurrence starting from 140°C which corresponds to the (P-V) center annealing temperature [12]. This indicates that for RTS an important role is played by cluster defects rather than isolated P-V defects which should exhibit an abrupt reduction of the unannealed factor. The measurements of main RTS properties for the two layouts and the results obtained by annealing process allowed having a guess for defect types that cause RTS switching of DCR. The identification of defects responsible of RTS and the understanding of its evolution in different conditions of temperature and bias voltage could be very useful to limit such effect on the devices operating in a radiation environment.

REFERENCES