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#09-218 Particle identification and tracking by the use of a pixel-based semiconductor radiation detector coupled with voltage controlled oscillators

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In this paper, an approach based on a semiconductor radiation detector exhibiting a matrix organization coupled with the use of rings oscillators for current detection is developed. This approach is based on the reading of the information related to indirect output parameters of the detection chain instead of directly measuring the current from the sensor. This solution is interesting because it avoids most of the design problems related to the use of a charge sensitive amplifier and keeps the current shape. Indeed, in applications such as gas prospection or medical therapy, the knowledge of the electrical signature of the particles is required. Moreover, knowing the actual shape of the generated current at the output of the detector allows easier post processing of the signal. Then, in our system, the information is extracted by correlating the initial oscillation of the system with that of the system after the particle has passed the detector (Fig. 1). To be able to make a diagnosis, the requirement is then to link the output information (i.e. the mean voltage of the oscillator) to the input information (current stimuli). The initial version of the chain was implemented in bulk technology. As the full integrated circuit (detector + readout electronic) is supposed to work in a radiative environment, the chain has been implemented on a 130nm partially depleted Silicon On Insulator (SOI) process, in order to make it more tolerant to radiation.

The detection chain has been simulated at circuit level using "Spectre"simulator (SPICE-based) under Cadence DFII ©. The readout circuits is composed of a ring voltage controlled oscillator (VCO) working at high frequency. Each VCO is composed of three specific delay cell in CMOS-SOI technology making their implementation very simple. This simplicity allows several configurations of use. The current source at the input of the VCO comes from the realistic simulation of the 3x5 matrix using TCAD device simulation tools (Synopsis ©). The effect of the ion strike is simulated using the Heavy Ion module of Synopsis [1], considering an electron-hole pair column centered on the ion track axis. The Linear Energy Transfer is defined as the energy lost by the particle, by unit of length [2]. An actual variation of the LET was integrated in our simulations, based on the value given by SRIM tables [3]. The VCO based chain presented here is optimized for the detection and identification of particle fluxes lower than 109 particles per detection area and per second. This chain could be particularly suitable for the detection of low energy particle such as alpha particle crossing the device with an initial energy of 0.9MeV, corresponding to a range of 2.3 µm in the silicon matrix . The aim is to study the end of the path corresponding to an alpha particle of 1.47MeV generated by the initial interaction of thermal neutron with boron-10. The case of a more energetic particle is also considered. This is a 50MeV Aluminum which could be produced by the interaction of fast protons with silicon, for instance [4].

In a previous work, the various currents generated in the matrix of detection were studied and several ways of improvement of the detection ability were explored [5]. We propose here a complementary solution to extract the total collected charge from the detector what should facilitate particle identification. Other particle species will be presented in the final paper.

After being generated by the sensor, the signal has to be conditioned in order to allow particles counting and/or recognition. The key point is how the output parameters of the VCO chain can give information related to the input current. This could be done through the analysis of various characteristics extracted from the VCO output voltage (Fig. 1) that is the variation of the average output signal (ΔVmax) versus the maximum of the input current (Imax) for different particle charges. In [6], a linearity curve linking input to output parameters was determined for a 2GHz VCO. A new linearity curve has been obtained for this new 4.3GHz VCO [5]. Through calibration curves, the output parameters can be linked to the input currents, which could allow the incoming particle tracking. The matrix studied here contains fifteen contacts (Fig. 2). All the currents of the matrix, generated using Synopsis have been injected in the fifteen VCOs contacts. The novelty in this work is that one more VCO is added in order to collect the the total collected charge. Indeed, the linearity of the VCO response may be affected if too high magnitude level of current is produced by the pixel detector, leading to a saturation of the VCO response. In order to overcome this limitation, we increased the size of the bias transistor of the delay cell composing the oscillator, leading to a high sensitive readout circuit but working a lower frequency. This second topology has been used for the total charge calibration. Then oscillator used at the bottom contact oscillates at 2.98GHz.

Fig.3 presents first results obtained with this VCO on four cases: an Al particle an alpha particle following two configuration corresponding to an horizontal crossing and a diagonal crossing of the cell. On the axis, the total collected charge at the bottom contact of the matrix is plotted. Its corresponds to the amount of charge collected in the whole structure. This gives a direct information about the deposited charge. Then the charge deposited by the Al particle is higher than the one of the alpha, and the charge collected for an horizontal track crossing 5.05µm is higher than the diagonal case crossing 2.82µm. Theses analysis will be details in the final paper. This trend is respected by the integral of the mean voltage value of the VCO. Then the linearity between the output and the input response is preserved (Fig.4). This will be checked for other particles species in the final paper. The tracking ability will be also detailed through the analysis of the currents from the fifteen other VCO.

Primary authors: COULIÉ, Karine (IM2NP - Aix-Marseille Université); RAHAJANDRAIBE, Wenceslas (IM2NP - Aix-Marseille Université); OTTAVIANI, Laurent (IM2NP - Aix-Marseille Université)

Presenter: COULIÉ, Karine (IM2NP - Aix-Marseille Université)

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