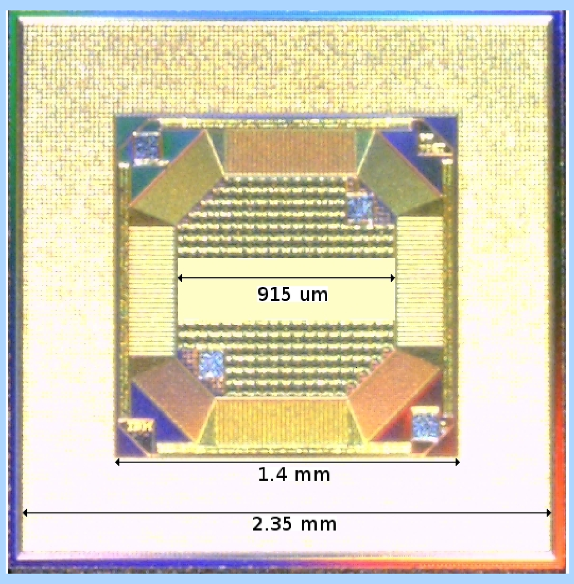
12th Pisa Meeting on Advanced Detectors

Radiation Tolerance of a Moderate Resistivity Substrate in a Modern CMOS Process

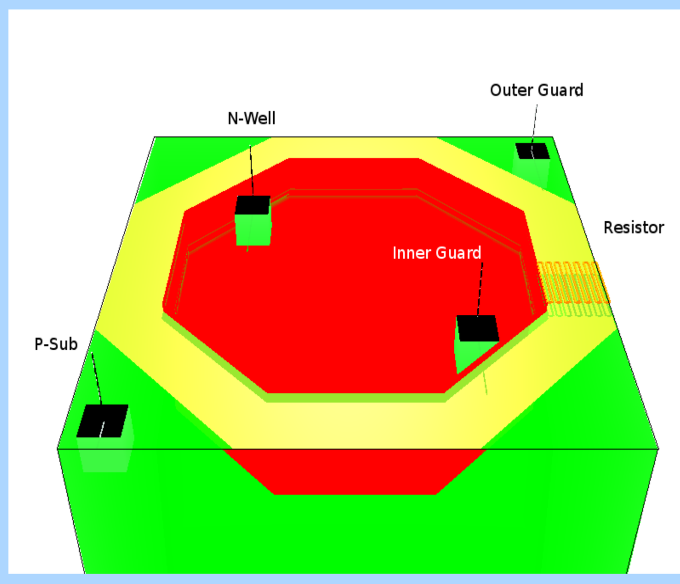
A. Potenza(1,2), D. Bisello(1,3), M. Caselle(1), N. Demaria(1), P. Giubilato(1,3), Y. Ikemoto(4), C. Mansuy(4), A. Marchioro(4), S. Mattiazzo(1,3), M.Moll(4), L. Pacher(1,2), N.Pacifico(4), D. Pantano(1,3), A. Rivetti(1), L. Silvestrin(1,3), W. Snoeys(2)
(1) INFN (2) Dipartimento di Fisica, Università di Torino
(3) Dipartimento di Fisica, Università di Padova
(4) CERN

The LePix project [1] aims at developing monolithic detectors integrating reverse biased detecting diodes and readout circuitry by porting a standard 90 nm CMOS process to higher resistivity substrates. Large diodes (about 1 mm^2) and pixel matrices prototypes were manufactured and exposed to both X-ray and neutron irradiations to investigate the radiation tolerance of the base material, which is an order of magnitude higher doped than standard high resistivity detectors.

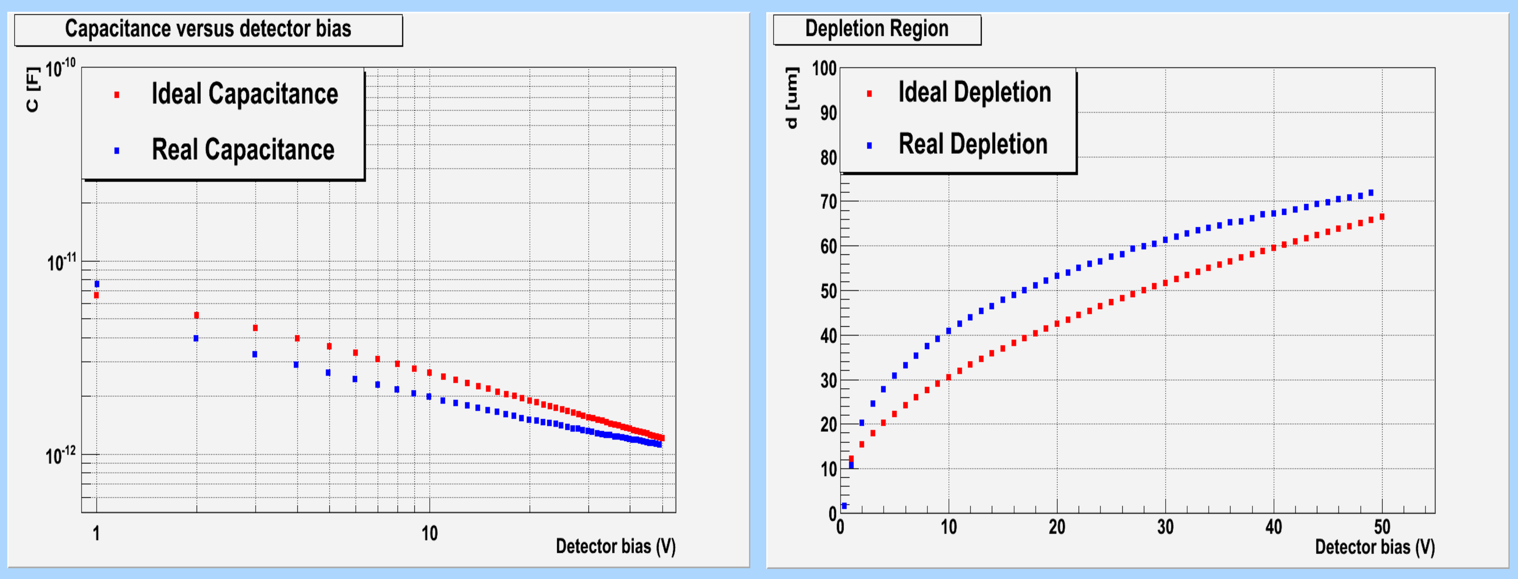
The diode is formed by an N-well implant in the high resistivity p-type substrate. It is equipped with a guard ring structure, which includes rings in poly silicon (imposed because of density rules in this deep sub micron technology) over field oxide which can be biased using a resistor.



Diode picture

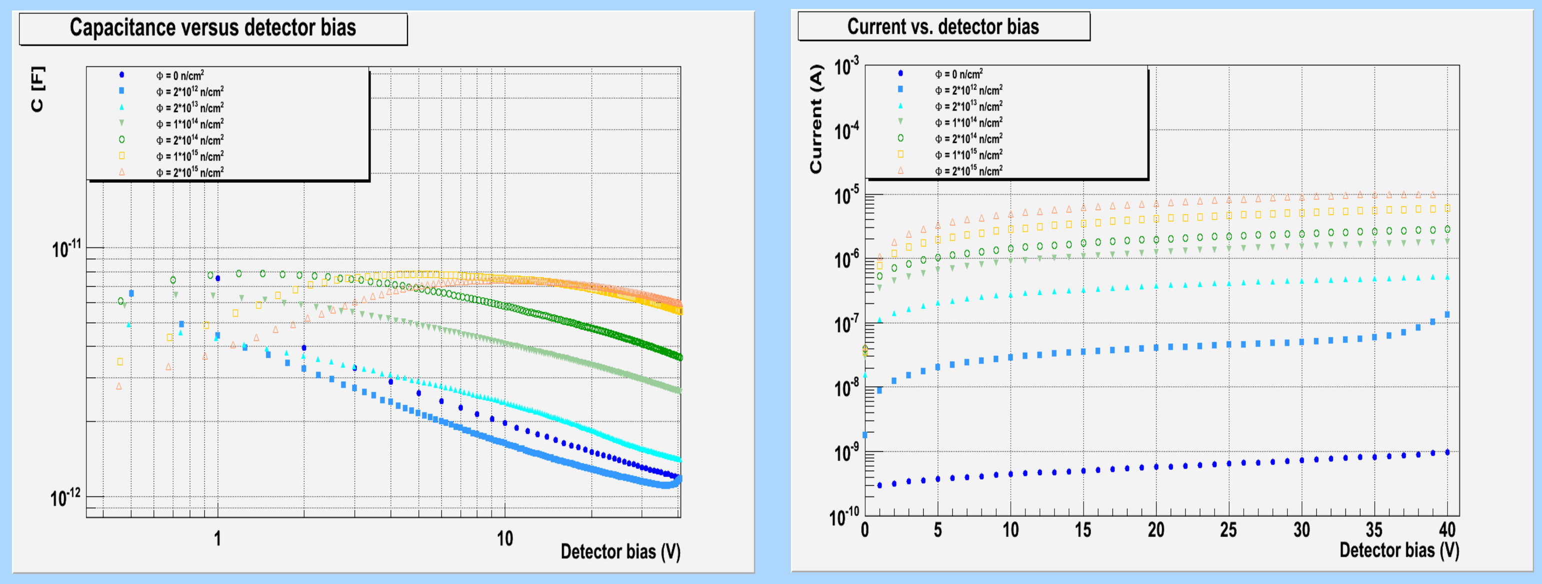


Schematic view of the diode with its contacts.

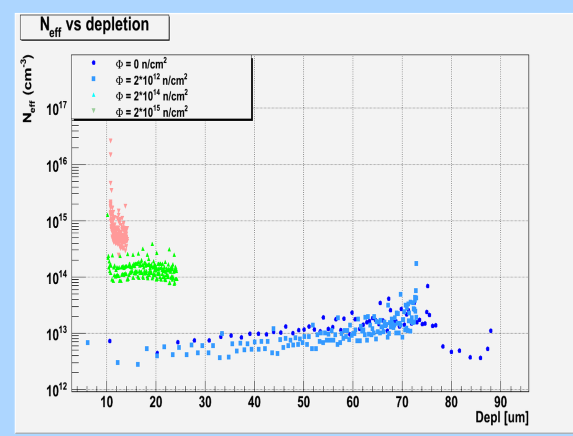


Comparisons between the real and ideal capacitance and the real and the ideal depletion region. The ideal capacitance has been obtained by supposing a planar and abrupt junction, a doping level of $1.5\cdot10^{13}$ cm^{-3} and a built-in potential of 0.7 V.

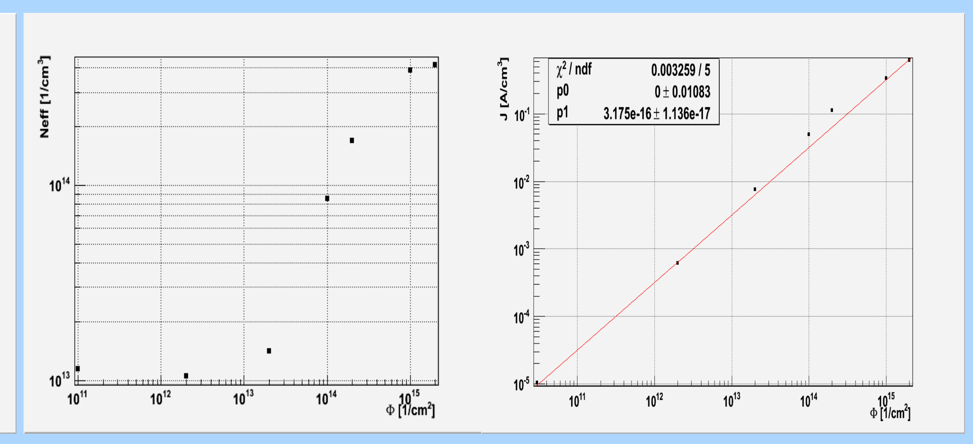
Neutron irradiations* have been carried out at the neutron irradiation facility in Ljubljana, with fluences varying between to $1\cdot10^{12}$ n/cm^2 and $2\cdot10^{15}$ n/cm^2. CV and IV measurements have been carried out on the irradiated large diode samples, from which doping level variation and leakage current damage rate ($\alpha = J/\Phi_{eq}$) have been extracted.



CV and IV curves for different neutron fluence values



Doping level vs depletion thickness for four different fluence value.

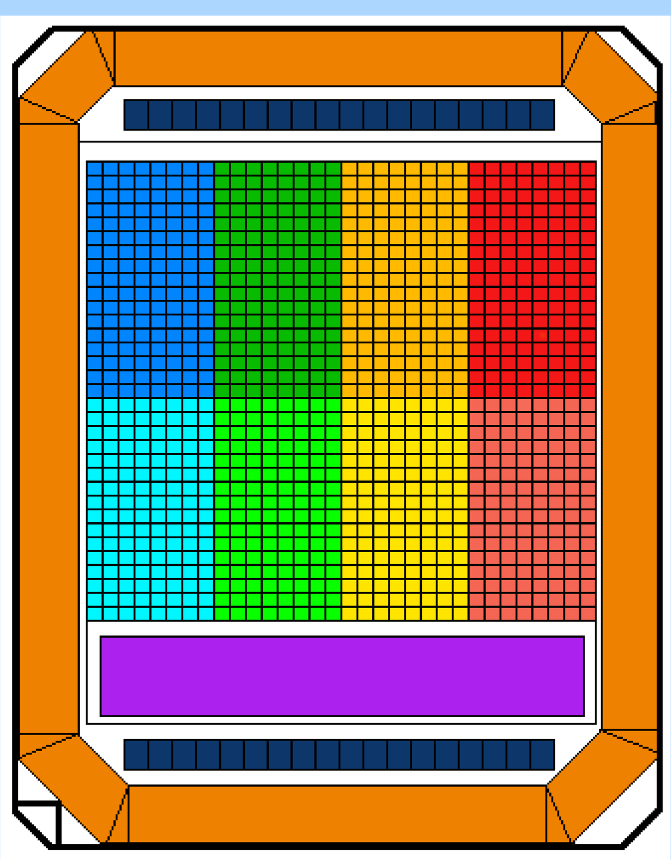


Doping level variation and leakage current damage rate estimation for V_{sub} = -24 V. Due to its exponential dependence on the temperature, the current is expressed at the reference temperature of T_R = 20°C following [2]:

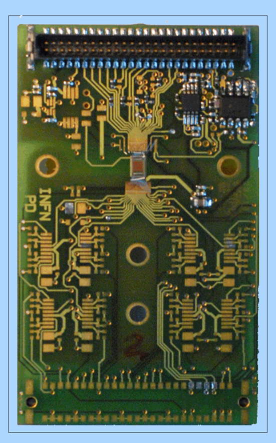
$$I(T_R)=I(T)\cdot R(T) \longrightarrow R(T)=\left(\frac{T_R}{T}\right)^2\cdot\exp\left[-\left(\frac{E_g}{2k_b}\right)\cdot\left(\frac{1}{T_R}-\frac{1}{T}\right)\right]$$

The value obtained for the leakage current damage rate is α = 3.18 ·10^{-16} A/cm which is higher than the value usually observed for traditional detector-grade silicon [3].

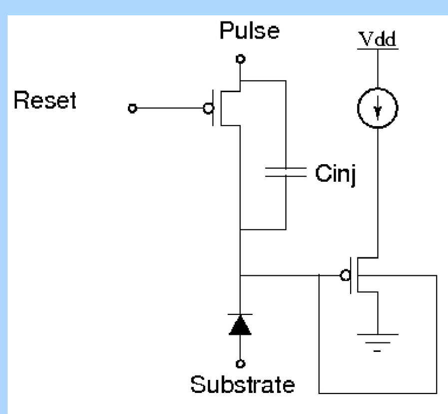
A 32x32 matrix of 50x50 μm^2 pixels with different collection electrode (N-well) sizes and different input transistors has been fabricated with a low power readout circuit based on correlated double sampling.



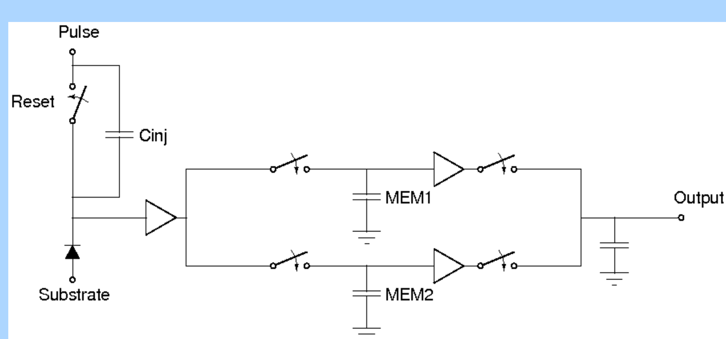
Layout of the matrix: the guard ring (gold), the four pixels types in Active Reset configuration (dark blue,dark green, dark yellow and dark red) and Continuous Reset configuration (clear blue, clear green, clear yellow and clear red), the back-end electronic (violet) and the pads (dark blue)



Test board

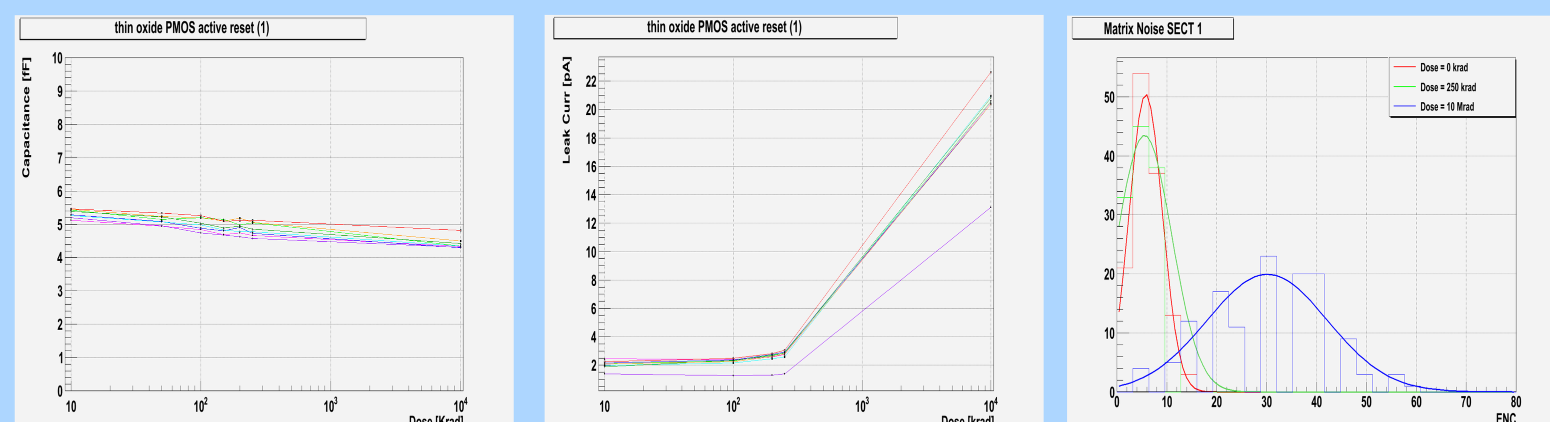


Pixel cell with the Active Reset transistor and the input transistor integrated in the N-Well (in the Continuous Reset configuration, the reset transistor is replaced by a diode)

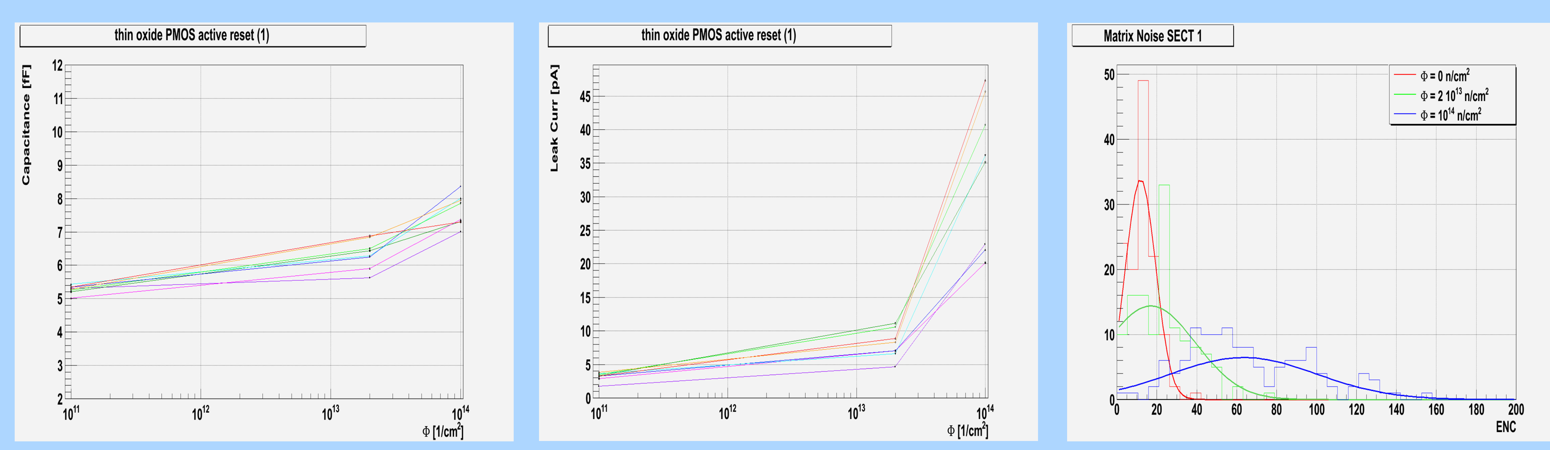


Front-end readout circuit

Matrices have been irradiated under bias with X-rays (10 keV) up to a 10 Mrad dose at low rate (5 krad/min) and with neutrons with no bias up to a 10^{14} n/cm^2 fluence.



Capacitance, current and noise evolution during X-Ray irradiation for the sector with the smallest collection electrode (N-well) in the pixel (room temperature). The last point has been taken after a 2 months annealing at room temperature. The noise histogram is given by the noise of all pixels of this sector.



Capacitance, current and noise evolution during neutron irradiation for the sector with the smallest collection electrode (N-well) in the pixel (T = -24°C).

[1] S. Mattiazzo at all, *LePix: First Results from a Novel Monolithic Sensor,* 12th Pisa Meeting on Advanced Detectors
[2] S.M. Sze, Semiconductor Devices Physics and Technology, John Wiley & Sons
[3] M Moll et all, *Relation between microscopic defects and macroscopic changes in silicon detector properties after hadron irradiation,*Nuclear Instruments and Methods

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