Design of CMS Pixels for an LHC Upgrade

J. Sibille[1,2], V. Radicci[2], T. Rohe[1]

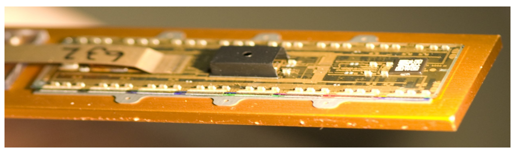
[1]Paul Scherrer Institut, Villigen, Switzerland

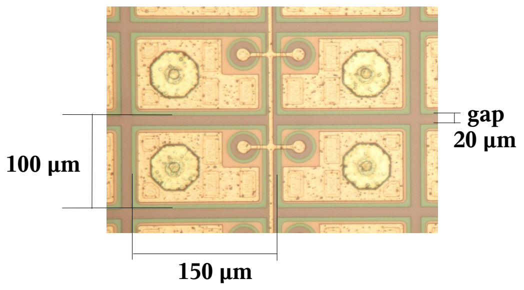
[2]University of Kansas, Lawrence, KS, USA

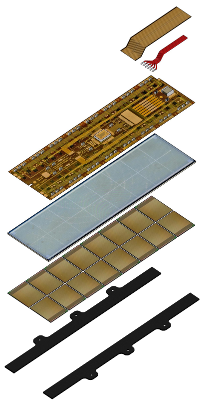
Introduction

Pixel detectors are used in the innermost part of multi purpose experiments at LHC and are therefore exposed to the highest fluences of ionizing radiation, which in this part of the detectors consists mainly of charged pions. The radiation hardness of all detector components has thoroughly been tested up to the fluences expected at the LHC. In case of an LHC upgrade, the fluence will be much higher and it is not yet clear how long the present pixel modules will stay operational in such a harsh environment. In order to establish such a limit, samples consisting of small pixel sensors bump-bonded to a CMS-readout chip have been irradiated with positive 200MeV pions at PSI up to $6\times10^{14}N_{eq}/cm^2$ and with 21GeV protons at CERN up to $5\times10^{15}N_{eq}/cm^2$. Different implant geometries as well as the possibility of single-sided sensors are also investigated.

CMS Pixel Barrel Module



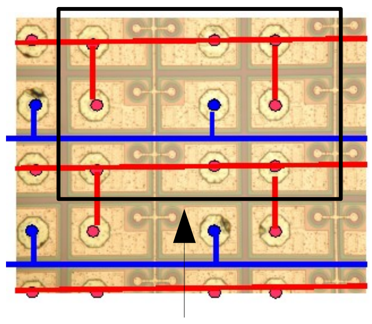




Inter-pixel Capacitance Measurement

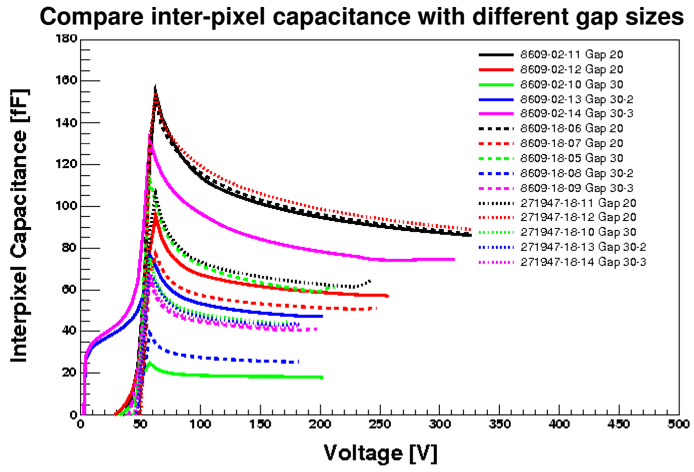
- Inter-pixel capacitance affects noise, cross talk between pixels, time walk of the ROC
- Dependent on bias voltage, gap size
- Designed “readout replacement chip” which was bump-bonded onto sensor

- Larger gap size has smaller capacitance
- Capacitance decreases as bias voltage increases
- Possible explanation: p-spray is being depleted
- Will investigate this effect with simulations
- Below depletion voltage pixels are interconnected
  - (n-in-n sensor)



1 pixel (blue) surrounded by 8 neighbors (red)

Compare inter-pixel capacitance with different gap sizes



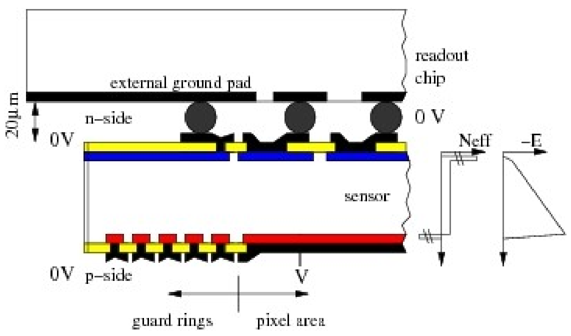
Sensor (“n-in-n” Type)

Collect electrons

- less trapping
- large Lorentz angle
- n-side isolation required (moderated p-spray)

“Easy” module construction

- All edges at ground potential
- Guard rings on back side
- n-substrate (chose DOFZ)



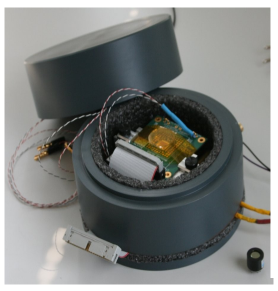
Radiation Hardness Study

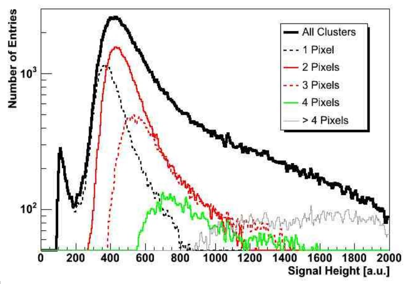
Signal collection: Studied using a Sr-90 source

- Low energy tail in Sr-90 spectrum
- Peak depends on cluster size
- Use only single hit clusters

Detection efficiency: Not studied here

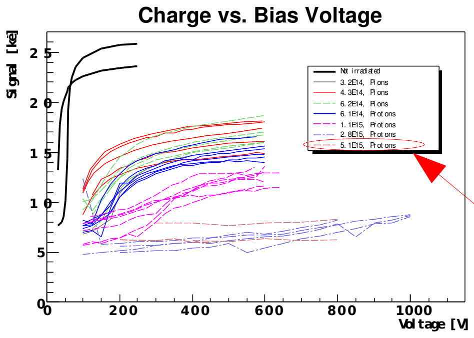
- (no independent trigger)



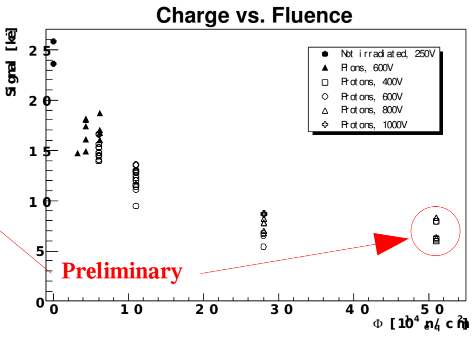


Results

Charge vs. Bias Voltage



Charge vs. Fluence



- Highly irradiated sensors operational up to bias > 1kV
- No signal saturation of the signal with bias for $\Phi > 2.8\times10^{15}N_{eq}/cm^2$
- Sensors with $\Phi = 2.8\times10^{15}N_{eq}/cm^2$ deliver >5000 electrons (at 800V)

Sensors with $\Phi = 5\times10^{15}N_{eq}/cm^2$ deliver signal between 5000-10,000 electrons (preliminary)

- So far shows no dependence on bias voltage in the range tested, needs to be verified

Signal is lower than reported by others

- No sign of multiplication

References

[1] T. Rohe, et al., Radiation hardness of CMS pixel barrel modules, contribution to the 11th European Symposium on Semiconductor Detectors, Wildbad Kreuth, Germany. Submitted to Nucl. Inst. and Meth. A (2009).

[2] T. Rohe, et al., Signal height in silicon pixel detectors irradiated with pions and protons, Nucl. Inst. and Meth. A (2009), doi:10.1016/j.nima.2009.08.012.

[3] T. Rohe, et al., Fluence dependence of charge collection of irradiated pixel sensors, Nucl. Inst. and Meth. A 552 (2005) 232.

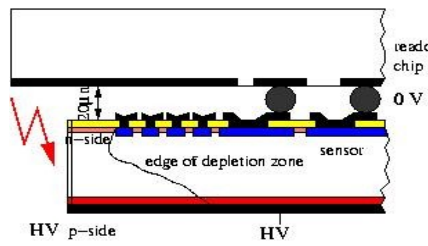
[4] A.Affolder,P.Allport,G.Casse,Studies of charge collection efficiencies for p-type planar silicondetectors after thermal neutron and 24MeV proton doses up to 2x10 16 neq/cm2, Nucl.Instr.and Meth.A(2009) doi:10.1016/j.nima.2009.08.005.

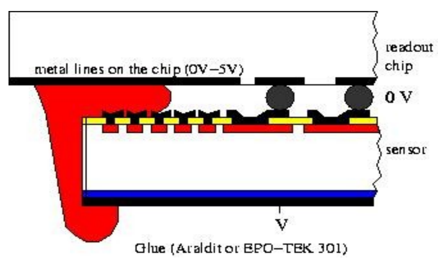
[5] I.Mandic, V.Cindro, G.Kramberger, M.Mikuz, Observation of full charge collection efficiency in pn strip detectors irradiated up to 3x10E16 neq/cm2, Nucl. Instr. and Meth. A(2009),doi:10.1016/j.nima.2009.08.004

Single-Sided Sensors

Exploring n-in-p sensors as alternative

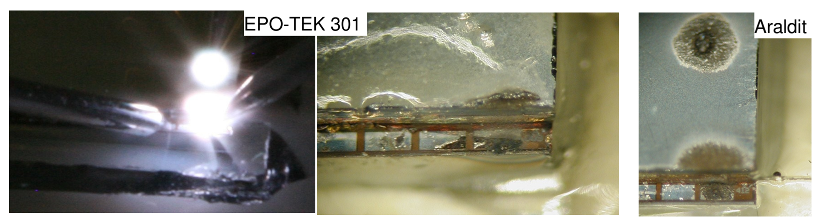
- Single sided process promises price benefit of factor 2-3
- Recent studies show radiation hardness
- Absence of guard rings on back side (HV) leads to **risk of sparking** to the ROC (0V)





To avoid sparking try to passivate edges with glue:

- Araldit (standard, used in CMS modules)
  - No change of breakdown (~500V)
- EPO-TEK 301 (very liquid, fills part of gap)
  - Breakdown at ~700V



Photos of sparking test results

Conclusions

- **Sensor delivers sufficient charge up to (at least) $3\times10^{15}N_{eq}/cm^2$ (~8cm layer in SLHC)**
- **High bias voltages deliver more charge at high fluences**
- **Larger gap between pixels reduces capacitance**
- **Sparking at high bias voltage is a problem in single-sided sensors, no solution found yet**

Acknowledgments

Thanks to the M. Glaser and M. Moll, CERN for the help with the proton irradiation, C. Betancourt and M. Gerling, UCSC for their help with the pion irradiation, and N. Krzyzanowski, UIC for her help with the measurements of the irradiated sensors. Part of this work was supported by the PIRE Grant OISE-0730173 of the US-NSF.