Signal simulation under the bias rail in n+-in-p pixel sensor before and after irradiation

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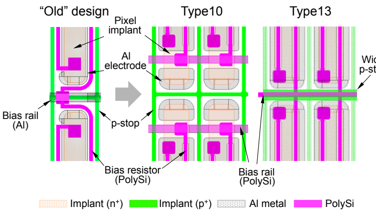
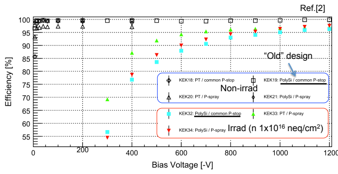
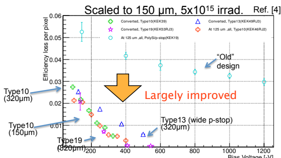
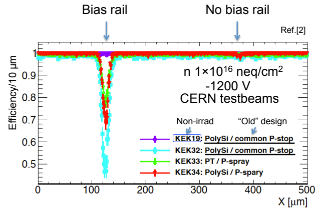
Abstract -- We have developed n+-in-p pixel sensors with biasing network to provide the reverse bias voltage to individual pixels without bumpbonding a readout ASIC. The pixel sensor with the bias rail running at the boundary between the pixels has shown a loss of track-finding efficiency under the bias rail when the device is irradiated with protons. The device has shown little efficiency loss initially. In this signal simulation, we have imported the electric fields and the weighting potentials from TCAD calculations. We have evaluated the charges lost to the bias rail from the distribution and drifting of the charge carriers in the silicon. A comparison of the results with or without radiation damage has confirmed the loss of efficiency quantitatively.

- Bias rail structure in n+-in-p pixel sensor Ref.[3]



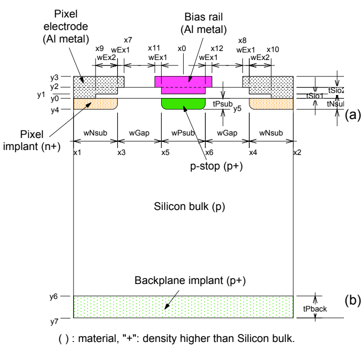


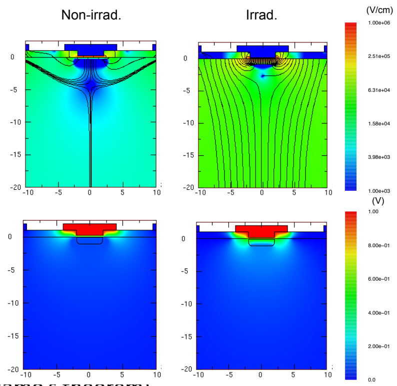




  - Efficiency loss after irradiation
    - large loss under the bias rail; little loss without the rail
    - ~3%/pixel (irrad); <~1%/pixel (non-irrad.)

- TCAD Simulation Ref.[5] for (a) Electric and (b) Weighting fields Ref.[3]
  - Geometry: vicinity of bias rail
    - p-type bulk, n+ readout, thickness 150 µm
  - Radiation damage approximation:
    - Increase of acceptor-like state ← Effective doping concentration
    - Increase of interface charge ← Fixed oxide charge
  - Non irrad. condition
    - N_{eff}=4.7×10^{12} cm^{-3}, V_{FD} ~40 V
    - Fixed Oxide Charge =1×10^{10} cm^{-2}
  - Irrad. condition
    - N_{eff}=1.5×10^{13} cm^{-3}, V_{FD} ~430 V
    - Fixed Oxide Charge =1×10^{12} cm^{-2}





- Induced charge to the bias rail (Ramo's theorem)
  - A mobile charge in the presence of any number of grounded electrodes, the induced charge Q_A at an electrode A is

$$Q_A = q \cdot V_{qA}$$

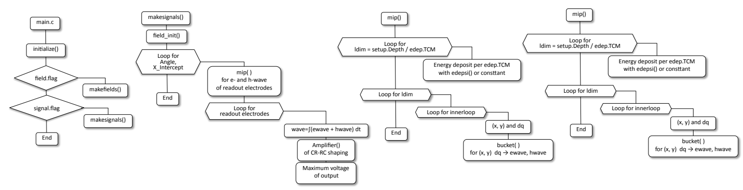
    - where q is the charge in a position, V_{qA} **the "weighting potential"** of the electrode A at the position of q.
  - In a finite time, with a fast readout circuitry, **instantaneous induced current, i_A, is the gradient of V_{qA} along the moving direction times the drift velocity**.

$$i_A = q\frac{dV_{qA}}{dt} = q\left(\frac{\partial V_{qA}}{\partial x}\frac{dx}{dt}\right) = q \cdot \vec{v_x} \cdot \frac{\partial V_{qA}}{\partial x}$$

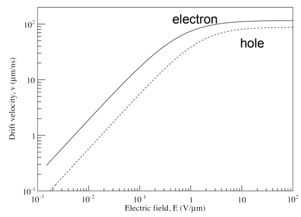
$$\vec{v_x} = \mu \vec{E_x} = \mu \frac{\partial V_x}{\partial x}$$

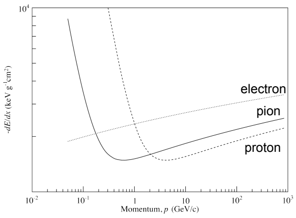
  - Although the final answer shall be obtained after integrating the current, we can have physics insight, **qualitatively**, from
E_x, v_x, V_{qA}

- Signal simulation
  - Using the simulation package Ref.[6] with various updates

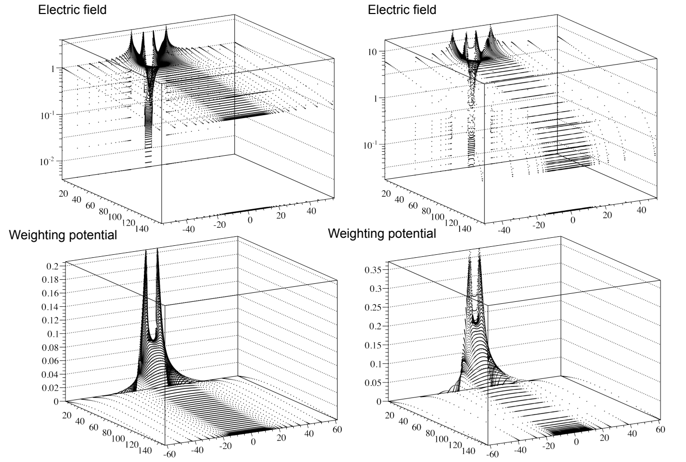


- Drift velocities Ref.[7], Energy deposition



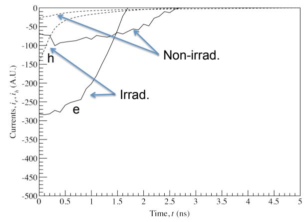


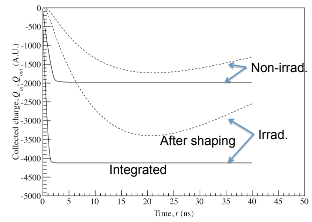
- Electric fields and Weighting potentials from TCAD
  - Non-irrad
  - Irrad.



  - Drift velocity is nearly saturated both in irrad. and non-irrad. as E > ~1 V/µm.

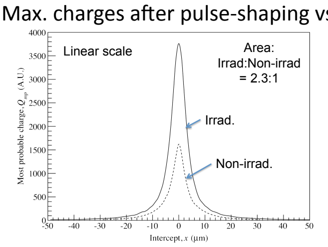
- Induced currents (e, h) and charges (integrated, after pulse-shaping)

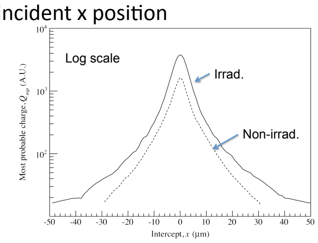




  - Bipolar nature of the current is not in the plot as the drift was cut off near the surface (at 3 µm) due to programming issue.

- Max. charges after pulse-shaping vs incident x position





- Summary
  - Charges lost to the bias rail is approximately 2.3 times in irrad. than in non-irrad. This explains the difference of efficiency loss in the irrad. and non-irrad, **quantitatively**.
  - The difference in intensity of charges lost is due to the difference in the convolution of the intensity of the weighting potential and the drift path as the drift velocity is nearly saturated in both irrad and non-irrad.

- References

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