Functional characterization of planar sensors with active edges using laser and X-Ray beam scans

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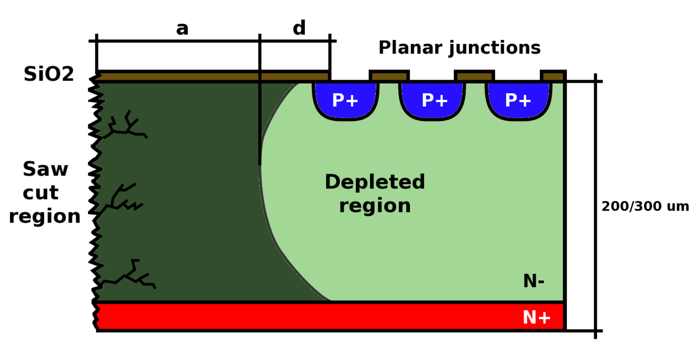
ABSTRACT - In the framework of our R&D activities oriented to 3D detectors, which finally led to the first production for the ATLAS Insertable B layer, we have also developed planar sensors with active edge. First proposed by C. Kenney et al., this type of edge termination consists of a deep trench etched all around the active area and doped as an ohmic electrode. One batch of these devices was fabricated at Fondazione Bruno Kessler, Trento, Italy, and the electrical characterization of the devices showed very good electrical behavior in terms of breakdown voltage and leakage currents. Here we report on the functional characterization of test diodes with active-edges performed by means of 1060nm laser scans carried out in our lab and by means of 15keV X-Ray beam scans carried out at the Diamond light source, UK. Measurements were performed on devices featuring different distances between the active area and the trench. Thanks to these measurements it was possible to investigate the effects of the bias voltage on the signal efficiency of the edge region (in particular the corner region) with different radiation sources and to demonstrate that devices work as expected. Preliminary results are very promising showing a full efficiency of the devices just $\sim 20\mu m$ away from the physical edge.

ACTIVE-EDGE MOTIVATION

Standard detectors

- Devices are extracted from the wafer by means of diamond saw
- The cutting line features cracks and dangling bonds
- A large distance (0.5-1mm)is required between the last junction electrode and the physical edge in order to prevent the depletion region to reach it and to insert proper terminating structures
- This results in a considerable waste of area that could otherwise be active

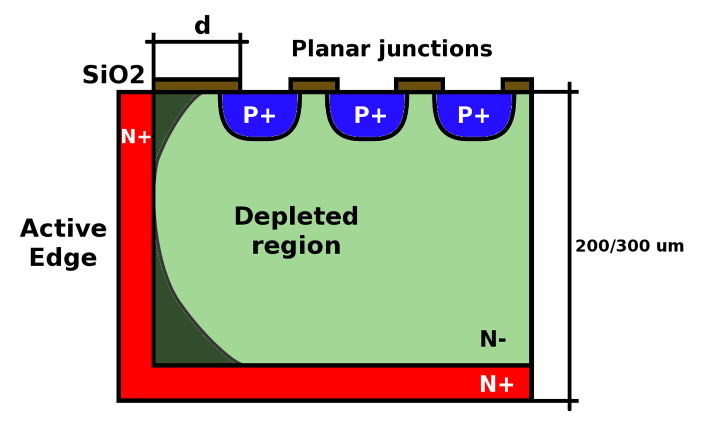


Active-edge detectors

- The cut lines are etched with Deep Reactive Ion Etching (DRIE) and doped
- This allows to drastically reduce the amount of dead area at the edges

Drawbacks

- The fabrication process is more complicated
- Support wafer needed
- It is essential to find the correct **"d"** to limit early breakdown phenomena



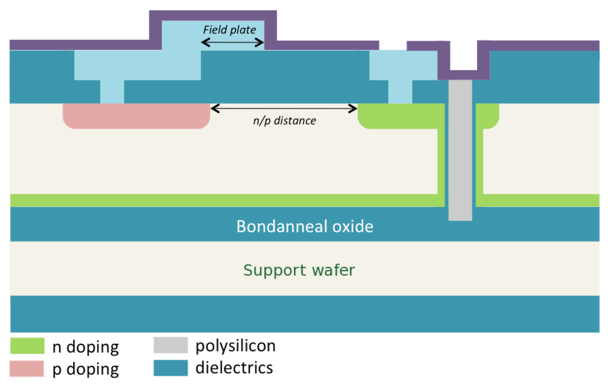
DEVICE DESCRIPTION

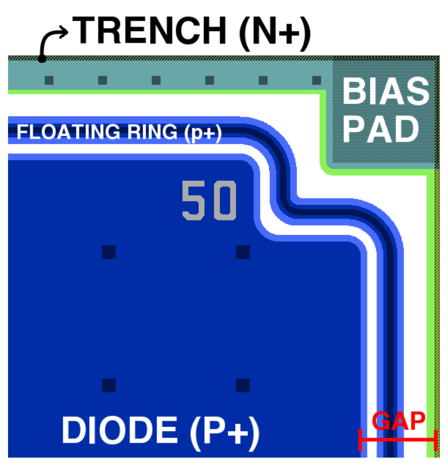
Device simulation and design

- Numerical simulations performed to find the best "GAP" distance
- Different layout solutions were tested in order to improve breakdown voltages
- Field-plates, Floating rings
- The optimal configuration is GAP$\simeq$50μm and field-plate length $\simeq 5\mu m$

Device fabrication

- N-type 4" wafer with <100> crystal orientation
- Bulk doping 2×10^{11} at.P/cm^2
- 6 lithographic masks
- The wafer bonding was performed as an external services at SINTEF (Oslo, Norway)
- Fabricated devices: diodes, strip detectors and pixel detectors





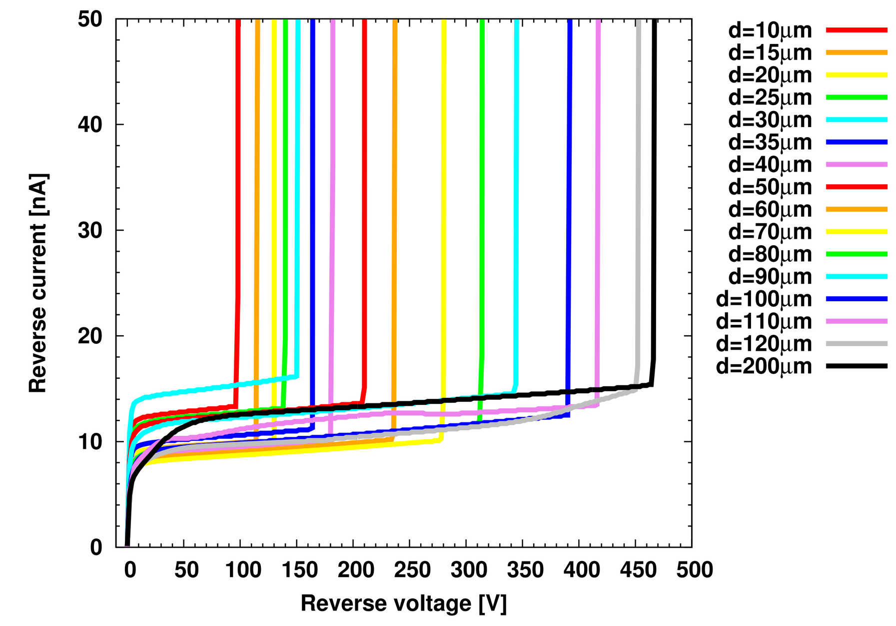
ELECTRICAL CHARACTERIZATION

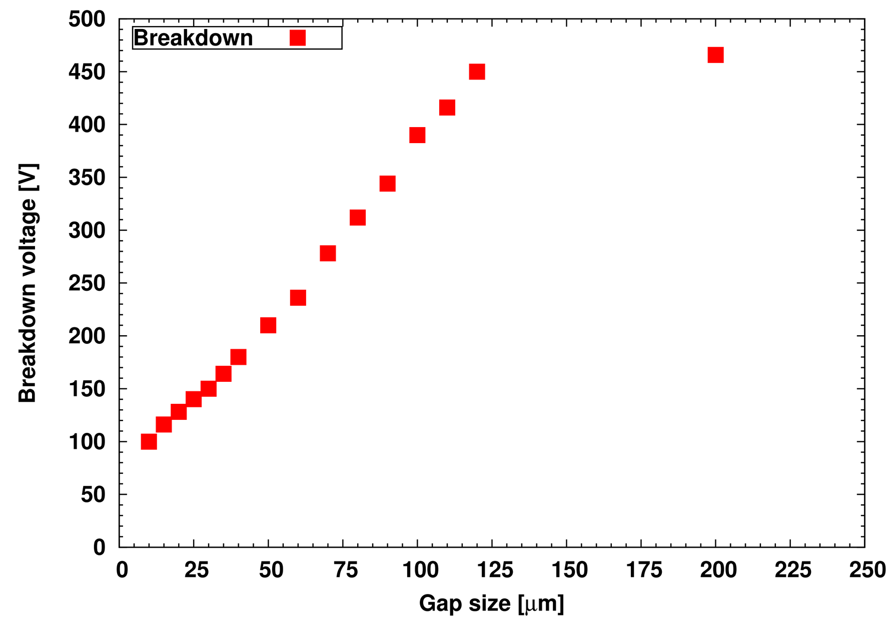
Devices geometrical properties

- Devices under test are planar diodes with active edges
- Easy to test and fully representative of the properties of the parent devices
- Several different flavors:
  - Several GAP distances (10-200μm)
  - Variable field plate lengths (0-24μm)
  - Different configurations with and without floating rings (0 to 3 rings)

Devices electrical properties

- Larger GAP distances correspond to higher breakdown voltages
- The field-plate generally helps increasing the breakdown voltage
- Floating rings have a similar effect but are less efficient because of the very small space between the electrode and the edge



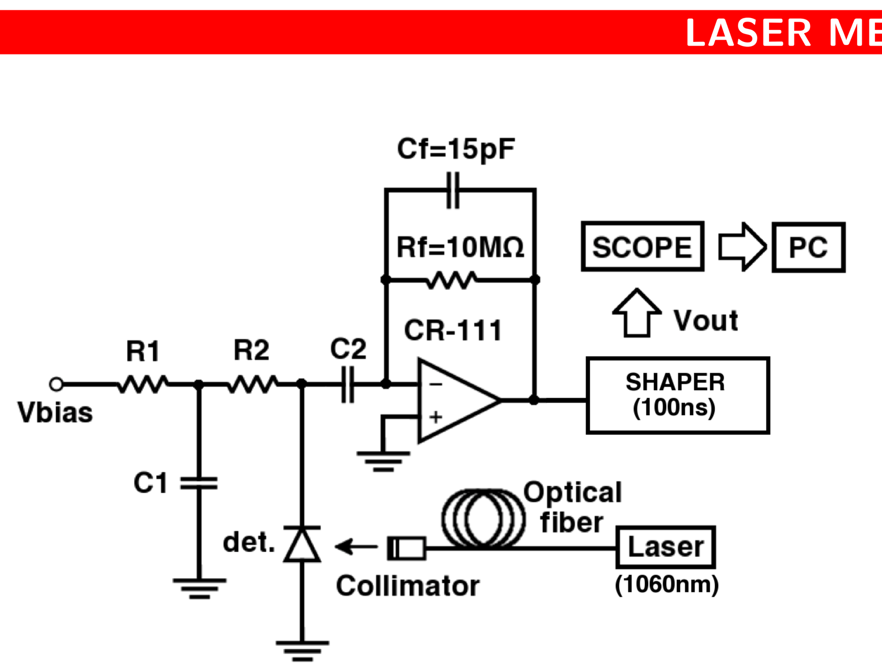


More details on design, fabrication and electrical characterization in [M.Povoli et al., NIMA 658 (2011) 103-107] and [G.-F. Dalla Betta et al., NSS2011 conference record, paper N25-4]

LASER MEASUREMENTS

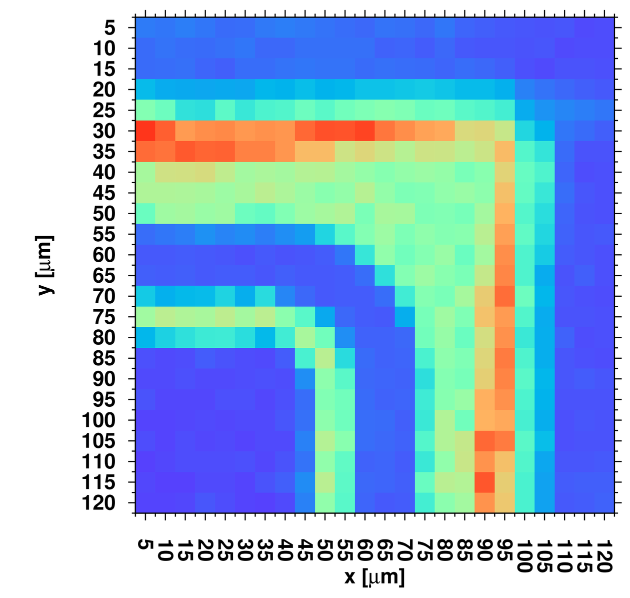
Experimental setup

- 1060nm laser (spot size $\sim 11\mu m$)
- Motors and positioning system (Thorlabs)
- Planar devices with active edges
- Cremat CR-111, Charge Sensitive Amplifier
- Cremat CR-200, Shaping amplifier (100ns peaking time)
- Tektronix 3052B scope
- PC to acquire data and move the laser



Laser scan of the corner region

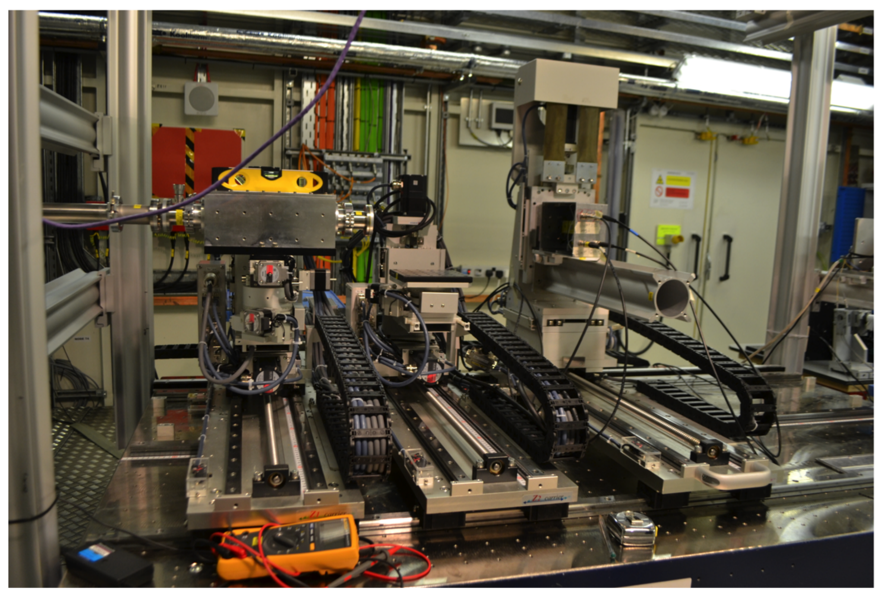
- GAP size 50μm
- Floating P$^+$ ring with metal on top
- Bias voltage 40V (full depletion $\simeq$5V)
- Scan step 5μm
- Possible to estimate the real GAP size to be $\simeq 50\mu m$
- Very good efficiency up to the physical edge
- Slightly higher efficiency at the edge because of thinner surface layers (better light transmission)



X-RAY BEAM MEASUREMENTS

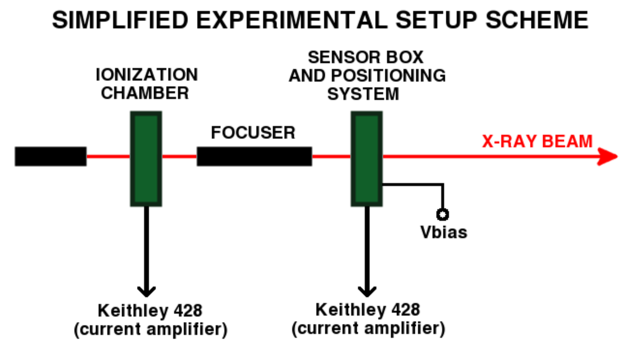
Beam line B16 at the Diamond Light Source

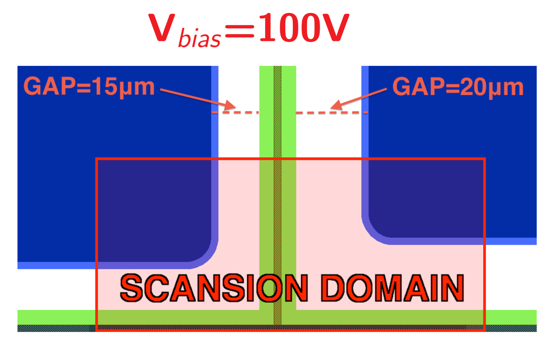
- In operation since the beginning of 2008
- It operates in the 2-20 keV photon energy range (monochromatic focused)
- Beam size at sample: 2-5μm in micro-focus mode
- Photon flux at 10 keV at sample: 7×10^{11}ph/sec/300mA in focused beam

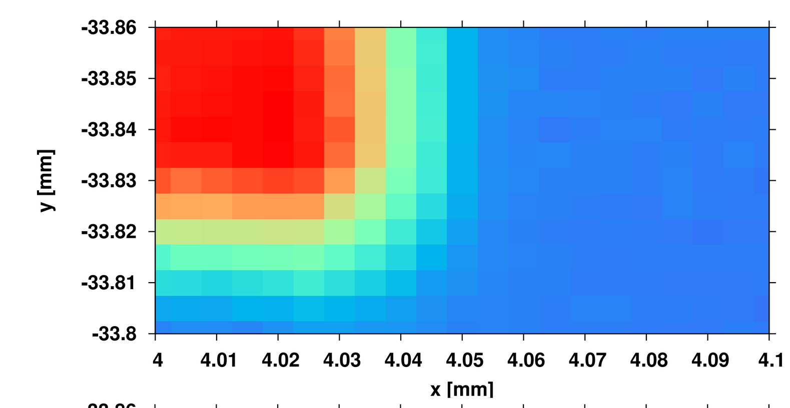


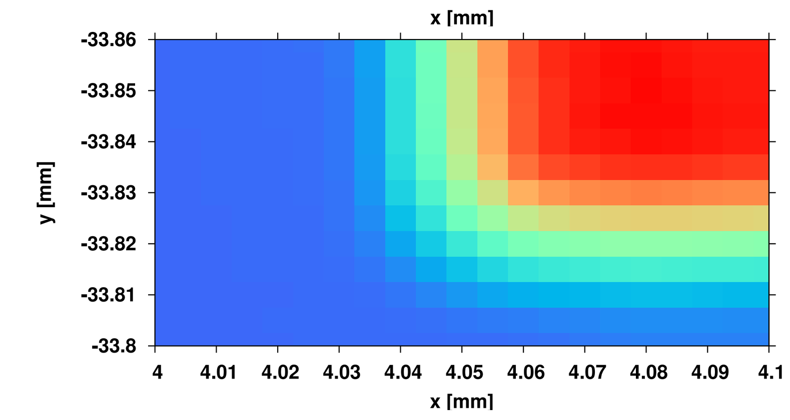
Experimental setup

- A ionization chamber is placed upstream from the focuser
- Devices under test are placed in a shielding box with an aperture covered with aluminum foil
- The box is placed on a sub-micron, 3-axes, positioning system
- Bias voltages are supplied using a NIM module
- The registered variation in leakage current is amplified with a Keithley 428 current amplifier and recorded for each point of the scan
- The detected signal is normalized using the reference given by the ionization chamber
- Results are expressed in arbitrary units









Measured data

- Two adjacent devices were connected to two separated output channels
- 5μm scan step both in 'x' and 'y'
- Different bias voltages (5,20 and 100V)

Results

- Very good efficiency even at low bias voltages
- 1D profile extracted at a constant y=-33.85mm
- Left diode: efficiency from 10% to 90% in 20μm
- Right diode: efficiency from 10% to 90% in 25μm
- The trench is larger than the designed width
- Full efficiency very close to the physical edge!