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Beam Test of a Large Area n-on-n Silicon Strip Detector with Fast Binary Readout Electronics

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A large area (60 mm $\times$ 60 mm), n-bulk and n-strip readout silicon strip detector was fabricated. The detector had a n-strip implant of 75 micron pitch and AC-coupled readout on the n-side, and one lithographed p-implant pad in the backside to make the p-n junction in the initial stage. Strips of 12 cm length were made by wire-bonding two detectors and were readout with pairs of a fast bipolar amp-shaper-discriminator chip and a CMOS digital buffer chip clocked at 40 MHz. The beam test was done for a non-irradiated detector and a detector irradiated with protons to a fluence of 1.2×10^{14} p/cm^2 and occasional warm-up before the beam test. Efficiency, noise, and spatial resolutions were measured by changing the threshold, the track angle of incidence, and the detector bias voltage from 50 to 280 V. The efficiency reached >99% at the bias voltage over 60 V for the non-irradiated detector and over 200 V for the irradiated detector, with a noise occupancy of about 10^{-4}, at a threshold of 1 fC. The implant strip under a polysilicon bias resistor was measured sensitive. A burst of noise, locally limited within less than 10 strips, was observed above a bias voltage coinciding with an increase of leakage current.

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Summary

A large area (60 mm × 60 mm), n-bulk and n-strip readout silicon strip detector was fabricated and beam tested using 4 GeV/c pions at KEK. The n-on-n detector was developed for a use in a high radiation environment to a charged particle fluence of more than 10^{14} p/cm^2. The detector had a n-strip implant of 75 micron pitch and AC-coupled readout on the n-side, and one lithographed p-implant pad in the backside to make the p-n junction in the initial stage. The n-side will become the p-n junction after the type-inversion from n-type to p-type bulk by radiation damage. The n-on-n detector should have a longer lifetime by allowing partially depleted operation after heavily damaged.

The beam test was done for a non-irradiated detector and a detector irradiated with protons to a fluence of 1.2×10^{14} p/cm^2 and occasional warm-up before the beam test. The beam test results indicated that the full depletion voltage was around 300 V at the time of the beam test. The detectors were operated at a temperature of -5 to 0 °C in the beam test, cooled with a cold Nitrogen-gas flow from the evaporation of the liquid Nitrogen. No humidity control was provided. The irradiated detector and the non-irradiated detectors were biased up to a bias voltage close to 300 V without any breakdown failure. The irradiated detector showed a thermal runaway at a bias voltage of 280 V.

Strips of 12 cm length were made by wire-bonding two detectors and were readout with pairs of a fast bipolar amp-shaper-discriminator chip and a CMOS digital buffer chip. Two kind of bipolar chips were used: one was named LBIC and the other ATT, a different implementation of the circuitry and the manufacturer. The digital buffer chips were clocked at 40 MHz. The non-irradiated detector was readout with the LBIC chips and the irradiated detector with the ATT chips.

Efficiency, noise, and spatial resolutions were measured by changing the threshold of the discriminator, the track angle of incidence, and the bias voltage to the detector from 50 V to 280 V. The bias dependence of the efficiency of the detectors are shown in Fig. 1 for the non-irradiated detector (UCSC2 module) and the irradiated detector (ATT4 module) at a threshold of 1 fC: 0.99 fC for UCSC2 and 0.92 fC for ATT4. The non-irradiated detector reached >99% efficiency at a bias voltage over 60 V and the irradiated detector over 200 V.

Electrical noise performance is shown in Fig. 2 in a form of the scatter plot of the efficiency and the noise occupancy. Each data point corresponds to an efficiency and an occupancy at a threshold setting which value is associated with the data point in the figure. A high efficiency of >99 % was achieved with a noise occupancy level of around 10^4 at a thresholds of 1 fC.

In the area of a polysilicon bias resistors (about 300 µm long), although no AC-electrode was provided in the detector, the implant strip under a polysilicon bias resistor was measured sensitive. A burst of noise was observed above a bias voltage in the non-irradiated detector, coinciding with an increase of leakage current. The number of noisy strips were locally limited within less than 10 strips.

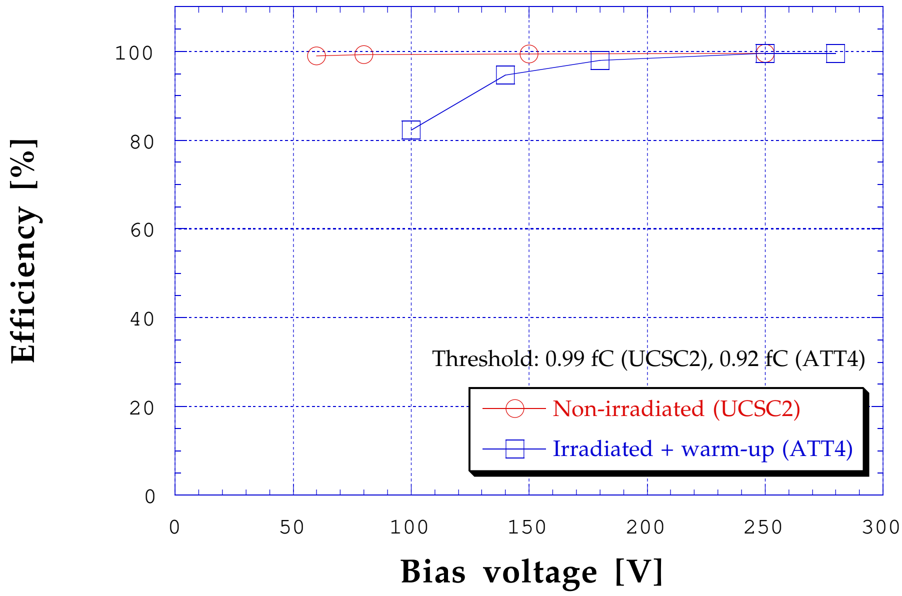

Fig. 1 Efficiency of the non-irradiated n-on-n detector (circle) and the detector irradiated to a proton fluence of 1.2×10^{14} p/cm^2 and warm-up (square) at a threshold of 1 fC as a function of the bias voltage.

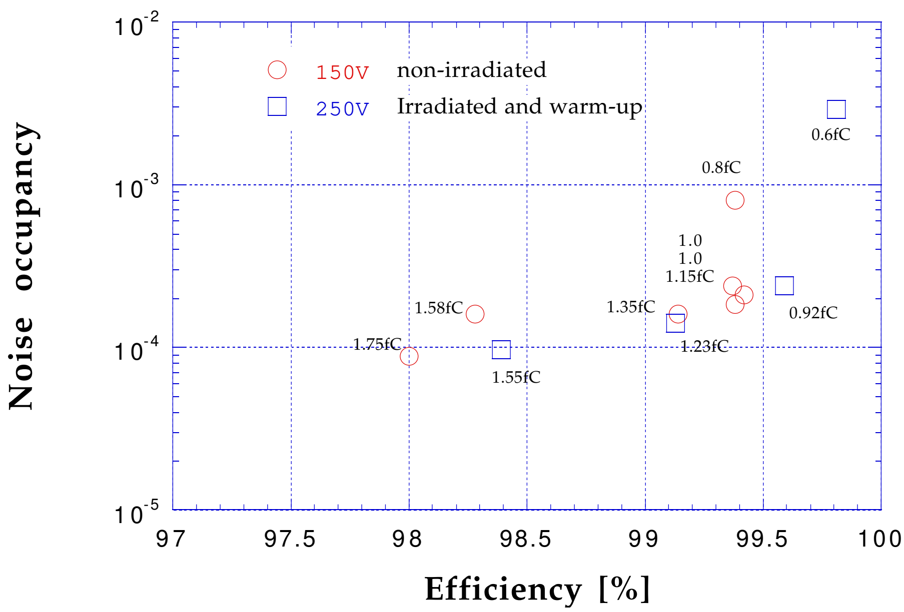

Fig. 2 Efficiency vs. noise occupancy in the non-irradiated n-on-n detector (circle) and the detector irradiated to a proton fluence of 1.2×10^{14} p/cm^2 and warm-up (square). The non-irradiated detector was readout with the LBIC chip at a bias voltage of 150 V, while the irradiated detector with the ATT chip at a bias voltage of 250 V. Each data point is the value obtained at a threshold setting which is associated with the data.