Characterization of thin n-in-p planar pixel sensors and status of the new active edge pixel production

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25th RD50 Workshop
19 - 21 November 2014
at CERN

Tested n-in-p Float Zone (FZ) sensors

VTT active/slim edges:

- FE-I3 100 μm
- FE-I4 100 μm
- FE-I4 200 μm

CiS production:

- FE-I4 200 μm
- FE-I4 200 μm
- FE-I4 300 μm

Irradiations:

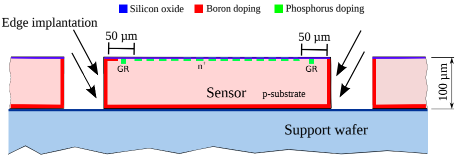
- 5×10^{15} $\mathrm{n_{eq}/cm^2}$ (1@KIT + 4@JSI)
- 5×10^{15} $\mathrm{n_{eq}/cm^2}$ (KIT)
- 6×10^{15} $\mathrm{n_{eq}/cm^2}$ (2@KIT + 4@JSI)

- 7×10^{15} $\mathrm{n_{eq}/cm^2}$ (LANSCE)
- 14×10^{15} $\mathrm{n_{eq}/cm^2}$ (LANSCE)
- 14×10^{15} $\mathrm{n_{eq}/cm^2}$ (LANSCE)

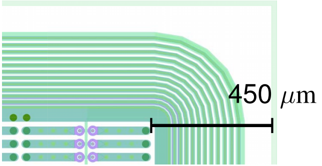
Irradiation facilities:

- JSI: $E \leq 10$ MeV reactor neutrons
- KIT: 25 MeV protons
- LANSCE: 800 MeV protons

VTT active/slim edge production



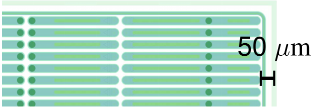
- four-quadrant ion implantation
  $\rightarrow$ activated edges



- 11 Guard Rings (GR) + 1 Bias Ring (BR)
  $d_{\text{edge}} = 450\ \mu\text{m}$

- 1 BR
  $d_{\text{edge}} = 125\ \mu\text{m}$

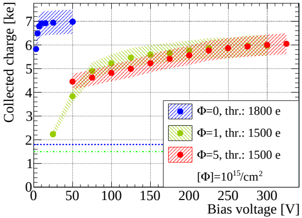
For edge analysis see MPP talk at last RD50 workshop by Stefano



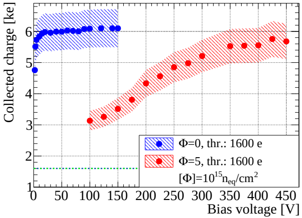
- 1 GR
  $d_{\text{edge}} = 50\ \mu\text{m}$

Charge collection of VTT modules

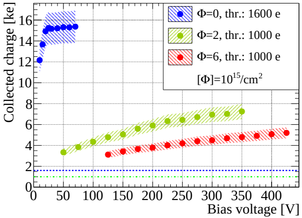
FE-I3 100 μm
5×10^{15} n_{eq}/cm^2



FE-I4 100 μm
5×10^{15} n_{eq}/cm^2



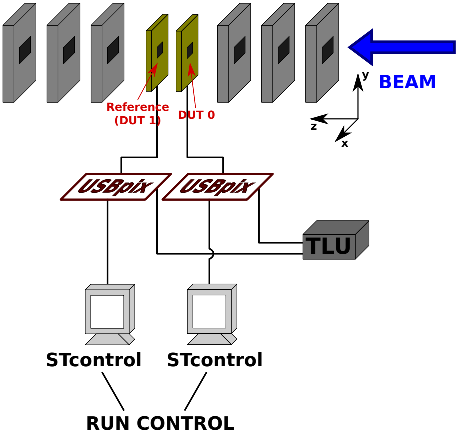
FE-I4 200 μm
6×10^{15} n_{eq}/cm^2

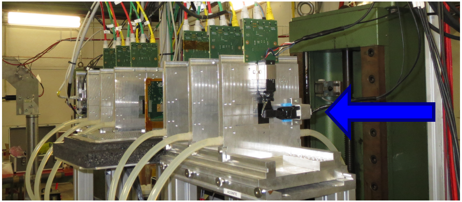


- CCE: (86 ± 12) % at $V_{\text{bias}} = 325$ V
- CCE: (95 ± 13) % at $V_{\text{bias}} = 425$ V
- CCE: (35 ± 5) % at $V_{\text{bias}} = 425$ V

- Charge collection of 200 μm sensor does not saturate below $V_{\text{bias}} = 425$ V

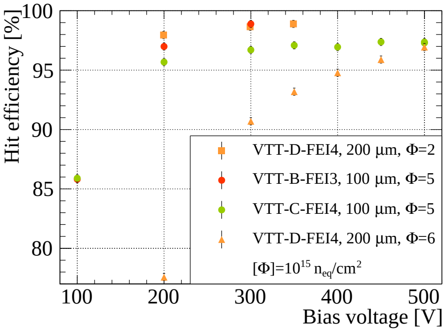
Test beam setup at DESY



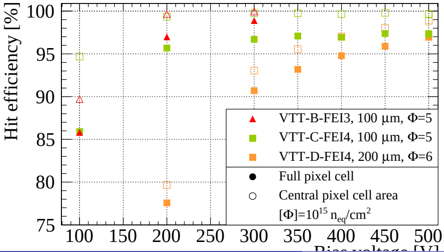


- 4 GeV electrons
- perpendicular incidence on the sensors
- track reconstruction with EUDET telescope

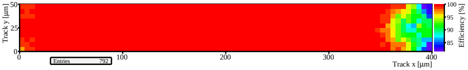
Efficiency of VTT modules



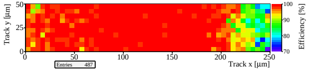
- FE-I3 100 μm: (99.1 ± 0.3) %
  $\Phi = 5{\times}10^{15}\ \mathrm{n_{eq}/cm^2}$, $V_{\mathrm{bias}} = 300\ V$
- FE-I4 100 μm: (97.3 ± 0.3) %
  $\Phi = 5{\times}10^{15}\ \mathrm{n_{eq}/cm^2}$, $V_{\mathrm{bias}} = 500\ V$
- FE-I4 200 μm: (96.9 ± 0.3) %
  $\Phi = 6{\times}10^{15}\ \mathrm{n_{eq}/cm^2}$, $V_{\mathrm{bias}} = 500\ V$



FE-I3 100 μm, $5{\times}10^{15}\ \mathrm{n_{eq}/cm^2}$



FE-I4 100 μm, $5{\times}10^{15}\ \mathrm{n_{eq}/cm^2}$



Power dissipation for different sensor thicknesses

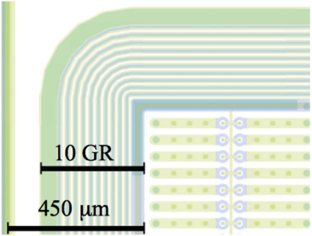
- Study the case of $\Phi = 5{\times}10^{15}$ - second pixel layer in the hypothesis of replacement at half the life-time of LHC
- Assume an operational bias voltage with 200 V of safety margin with respect to the voltage for which a hit eff. of 97-98 % can be obtained

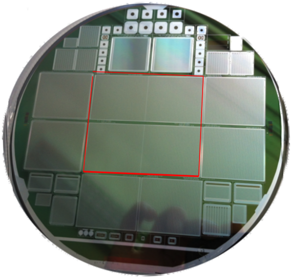
Thickness [μm]	Op. V_{bias} [V]	$I_{\mathrm{leak}}(-25^{\circ}C)$ [$\mu\mathrm{A/cm^2}$]	Power [$\mathrm{mW/cm^2}$]
100	500	35	18
200	700	65	45

- Reduced risk of thermal runaway for thin sensors in the inner layer

CiS production

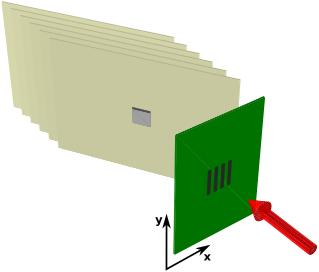
- 200 μm thick n-in-p pixel sensors produced at CiS on 4 inch FZ silicon wafers
- Bump-bonded on ATLAS FE-I4 chips at IZM
- Spark protection with 3 μm layer of patterned BCB deposited on the sensor surface at IZM
- GR structure with 450 μm inactive edge



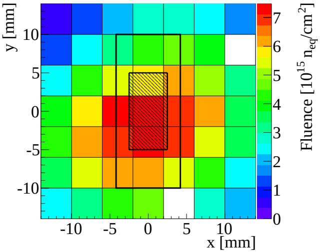


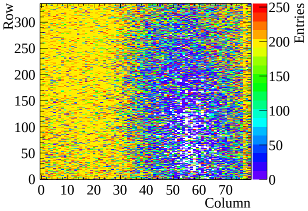
Irradiation of CiS modules at LANSCE

- 7×7 diode array perpendicular to beam to measure beam profile + aluminum foil for dosimetry
- $2 \times 2\ \mathrm{cm}^2$ sensors and $1 \times 1\ \mathrm{cm}^2$ Al foil titled at 30° degree w.r.t. the beam



Fluence according to diodes and foil

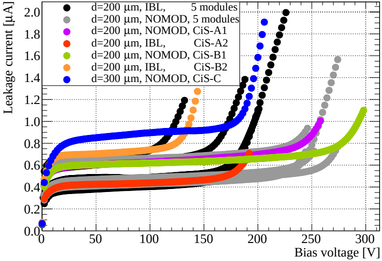




Analog scan of module irradiated to $7{\times}10^{15}\ \mathrm{n_{eq}/cm^2}$ (rotated by 90° degree w.r.t. diode array)

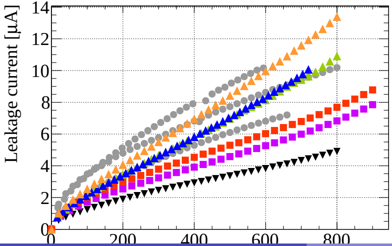
IV curves of CiS sensors

IV curves before irradiation



- Given the inhomogenous irradiation the leakage currents cannot be directly compared between LANSCE and KIT irradiated modules as curves do not scale linearly with the nominal fluence

IV curves after irradiation



d=200 µm, NOMOD, Φ=5 (KIT), 3 modules

d=200 µm, IBL, Φ=2 (KIT), CiS-KIT-2e15

d=200 µm, NOMOD, Φ=7 (LANSCE), CiS-A1

d=200 µm, IBL, Φ=7 (LANSCE), CiS-A2

d=200 µm, NOMOD, Φ=14 (LANSCE), CiS-B1

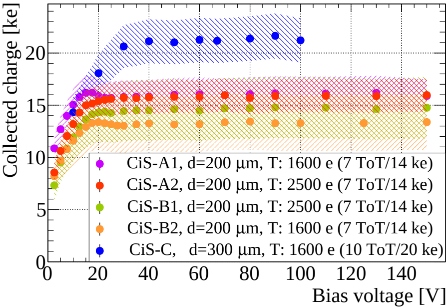
d=200 µm, IBL, Φ=14 (LANSCE), CiS-B2

d=300 µm, NOMOD, Φ=14 (LANSCE), CiS-D

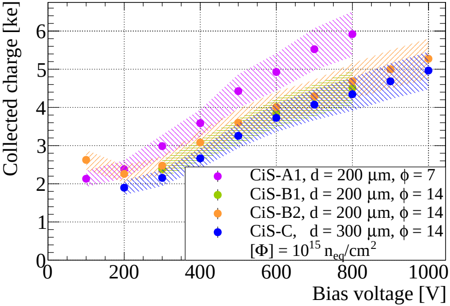
$[\Phi] = 10^{15}\ n_{eq}/cm^2$

Charge collection of CiS modules

Before irradiation



After irradiation



Expected charge in silicon:
14 ke for 200 μm
21 ke for 300 μm

CCE of 200 μm sensors:

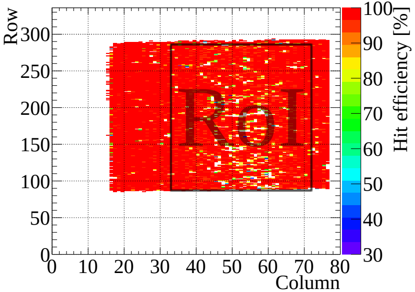
- 7×10^{15} n_{eq}/cm^2 $\rightarrow$ (45 ± 6) %
- 14×10^{15} n_{eq}/cm^2 $\rightarrow$ (35 ± 5) %

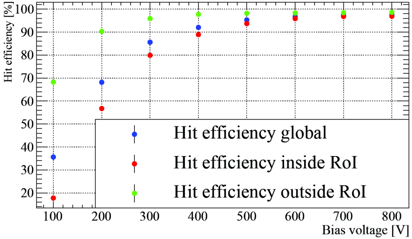
CCE of 300 μm sensors:

- 14×10^{15} n_{eq}/cm^2 $\rightarrow$ (25 ± 4) %

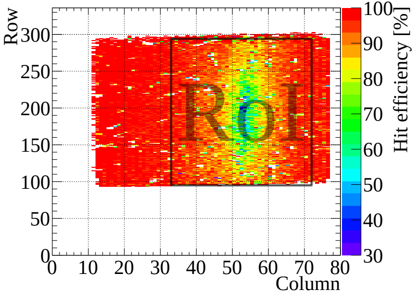
Effiency of CiS modules irradiated at LANSCE

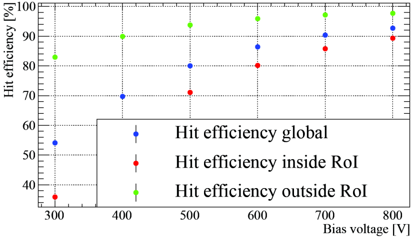
200 μm, 7×10^{15} $\mathrm{n_{eq}/cm^2}$, thr. 1600 e





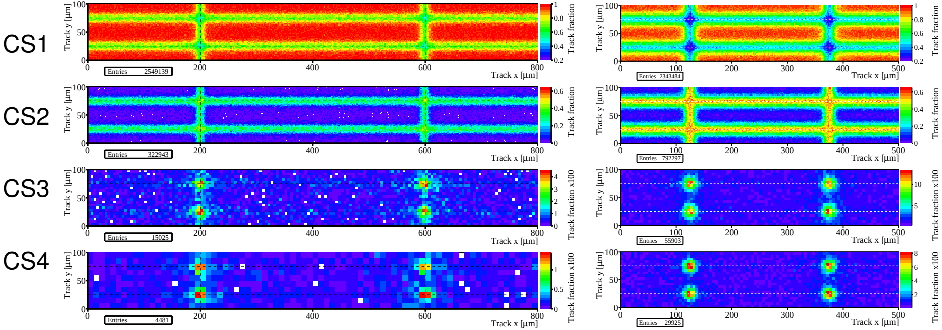
200 μm, 14×10^{15} $\mathrm{n_{eq}/cm^2}$, thr. 1600 e





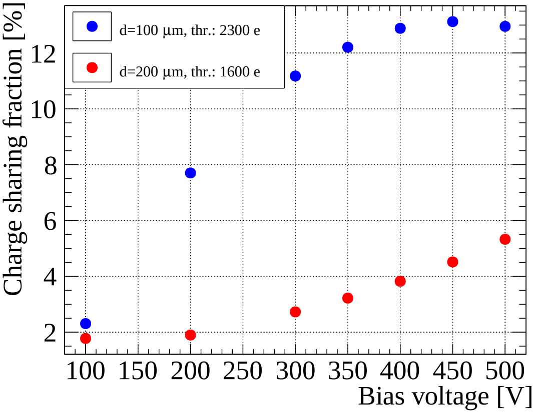
Charge sharing for unirradiated modules

FE-I3 100 μm, thr. 1800 e — FE-I4 200 μm, thr. 1600 e



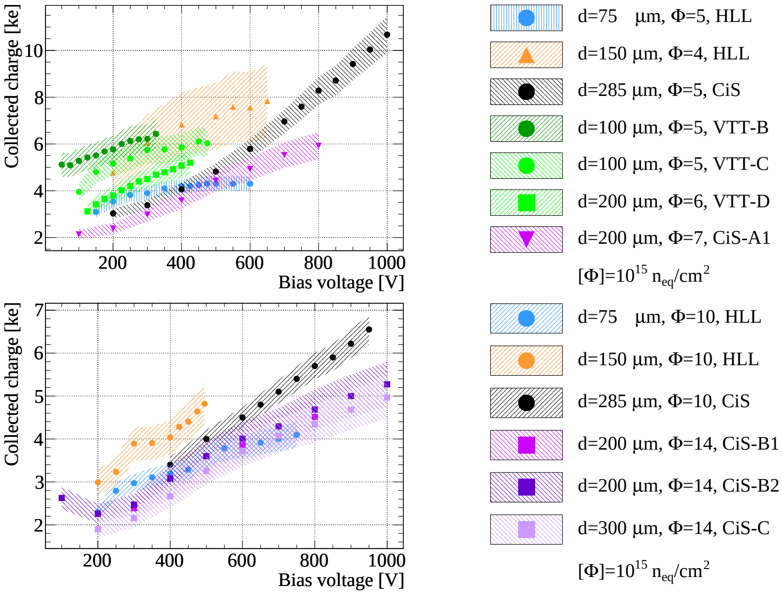
- Maximum spread of charge cloud for 100 μm sensor at $V_{\text{bias}} = 20\ V$ is about 5 μm
- Maximum spread of charge cloud for 200 μm sensor at $V_{\text{bias}} = 50\ V$ is about 7 μm
- Measured at the same time, therefore same telescope resolution of about 7 to 10 μm for both modules
- Observed charge sharing increased in FE-I4 probably due to lower threshold in the measurement (1600 e vs 1800 e)

... Charge sharing for irradiated modules



- After irradiation the effect of charge sharing is stronger for the 100 μm thick sensors than for the 200 μm thick sensor due to the higher charge collection and the higher electric field at equal bias voltages

Summary of charge collection properties

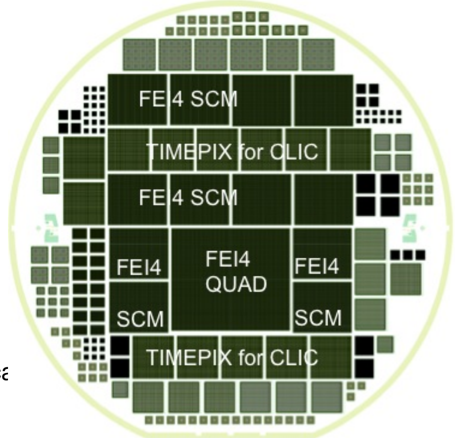


2nd production of active edge pixels at ADVACAM

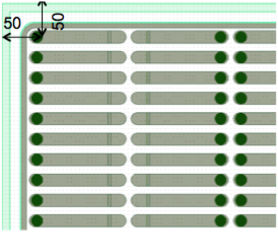
- In collaboration with Glasgow, Göttingen, LAL, CLIC CERN-LCD, Geneva University for medical applications

- **50, 100, 150 μm thick sensors (5 FZ p-type wafers for each thickness):**
  - FE-I4 quad sensor
  - FE-I4 single chip sensors with different geometries
  - Omegapix sensors
  - TIMEPIX sensors for CLIC R&D
  - CLICpix sensors for CLIC R&D
  - Pixel and strip structures for medica applications

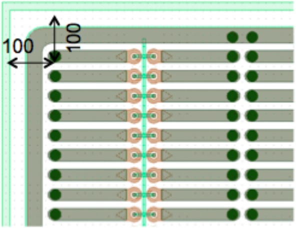
Active edge process for all structures



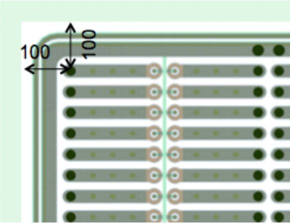
FE-I4 Single Chip Modules



FE-I4
50 μm edge
one Guard Ring,
no punch-through
structures

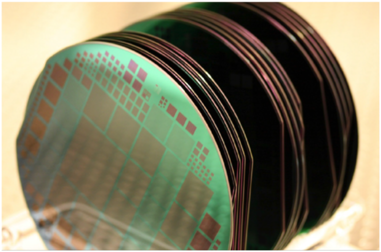


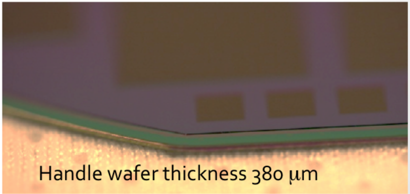
FE-I4
100 μm edge
Bias Ring
punch-through
structures



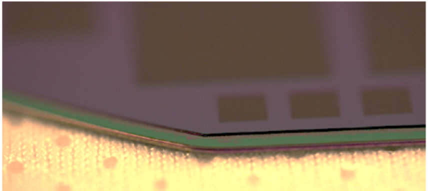
FE-I4
100 μm edge
Bias Ring + Guard Ring
punch-through
structures

Status of the new ADVACAM production

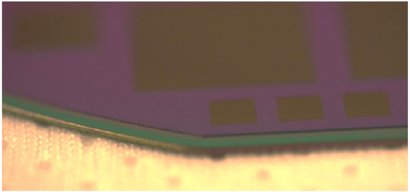




50 um



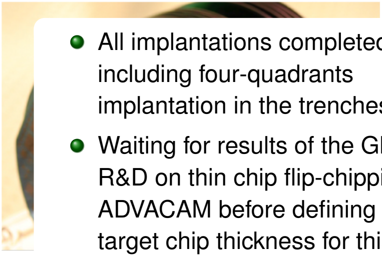
150 um

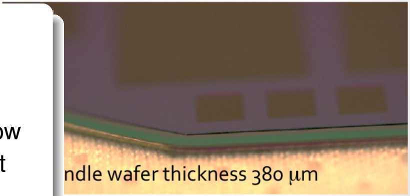


100 um

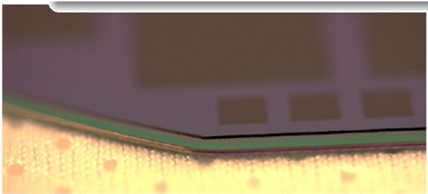
Status of the new ADVACAM production

- All implantations completed including four-quadrants implantation in the trenches
- Waiting for results of the Glasgow R&D on thin chip flip-chipping at ADVACAM before defining the target chip thickness for this production

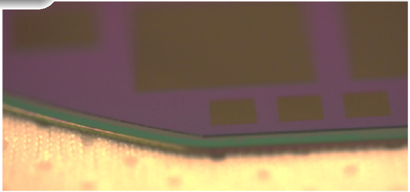




50 um



150 um



100 um

Conclusions

- Good charge collection and hit efficiency for 100 μm thick sensors with and without active edges
- Studies performed with 200 and 300 μm thick n-in-p sensors up to a fluence of $14\times10^{15}\ \mathrm{n_{eq}/cm^2}$
  $\rightarrow$ modules are still functional after a very inhomogenous irradiation

And future plans ...

- Characterize thin pixel sensors at higher fluences ($\geq 10^{16}\ \mathrm{n_{eq}/cm^2}$) with new productions at ADVACAM (50, 100, 150 μm thick with active edges) and CiS (100-150 μm thick)
- $\rightarrow$ see talk by T.Wittig on R&D avtivities at CiS