Silicon Detector R&D in DT

EP-DT Group Meeting

09/12/2021

Florian Dachs (EP-DT-DD)
Katharina Dort (EP-DT-TP)
Anja Himmerlich (EP-DT-SSD)

Pixel detector R&D in DT-TP

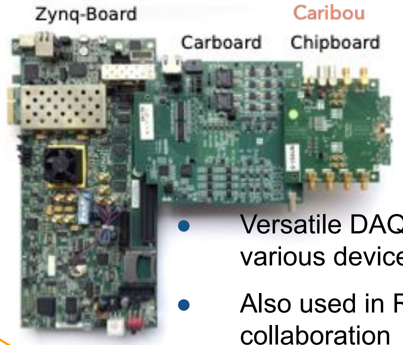
EP-DT
Detector Technologies

- Pixel detector R&D for future collider detectors, emphasis on Higgs factories
  - High precision, low mass
- Pursued within EP R&D programme and various collaborative frameworks (AIDAinnova, CLICdp) and strong connection to EP-ESE + DESY + UniGE
- Simulation-based sensor optimisation and experimental verification with technology demonstrators
- **Team members: Justus Braach, Eric Buschmann, Dominik Dannheim, Katharina Dort, Peter Švihra**

Caribou readout system

PoS 2020 (TWEPP2019), 100

https://gitlab.cern.ch/Caribou



- Versatile DAQ for various devices
- Also used in RD50 collaboration

Test-beam infrastructure

- Built + maintain high-rate telescope at SPS

Software tools for the (HEP) community

- Corryvreckan test-beam reconstruction and analysis
- Allpix Squared Monte Carlo simulation framework for end-to-end simulation of silicon sensors

https://gitlab.cern.ch/corryvreckan/

2021 JINST 16 P03008

https://gitlab.cern.ch/allpix-squared/allpix-squared

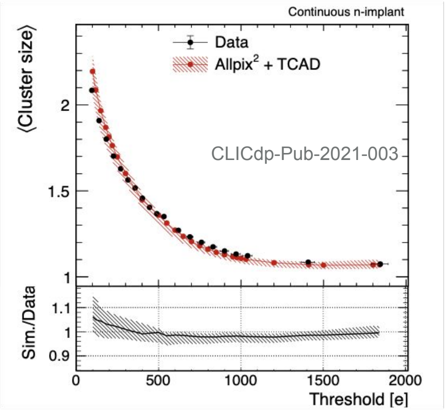
NIM A 901 (2018) 164-172

Pixel detector R&D in DT-TP

Sensor Optimisation

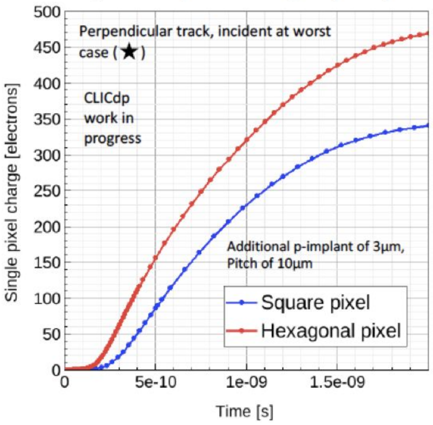
- Combined electrostatic 3D TCAD + transient MC simulation for
    - Precise sensor modelling
    - High simulation rates

NIM A 964 (2020) 163784



- Design optimisation for fast sensor timing
- Hexagonal pixel layout for improved performance

3D TCAD Simulation

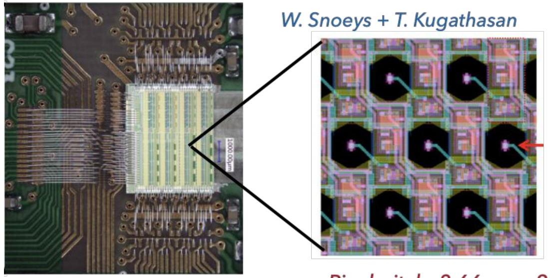


NIM A 979 (2020) 164461

Monolithic CMOS sensor with sub-nanosecond timing

- Modified 180 nm CMOS imaging process

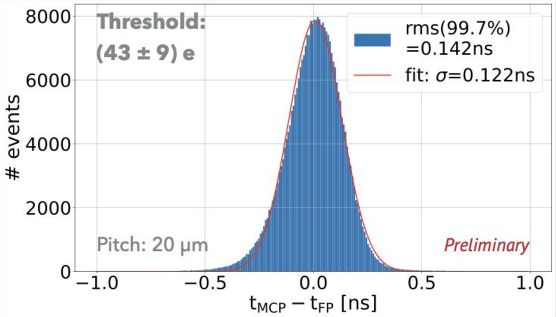
Hexagonal pixel layout



W. Snoeys + T. Kugathasan

Pixel pitch: 8.66 µm - 20 µm

- Time resolution < 150 ps

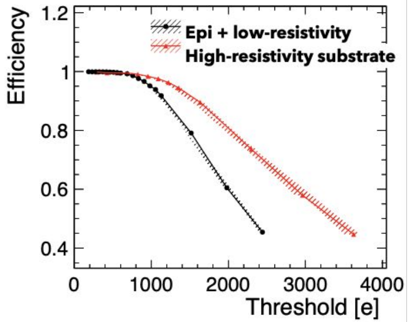


Pixel detector R&D in DT-TP

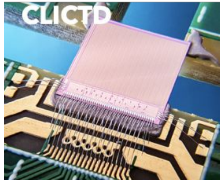
Advances materials for monolithic sensors

- Larger active sensor volume
  - Improved detector performance: efficiency, spatial + time resolution

https://agenda.linearcollider.org/event/9211/contributions/49443/



EP-DT
Detector Technologies



STREAM

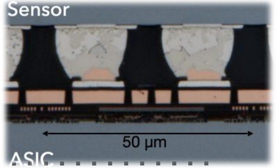
NIM A 986 (2021) 164381

Novel fine-pitch hybridisation

- Development + characterisation of small-pitch (25 µm) bump-bonding process

CERN-THESIS-2020-338

CLICpix2 hybrid assembly (IZM)

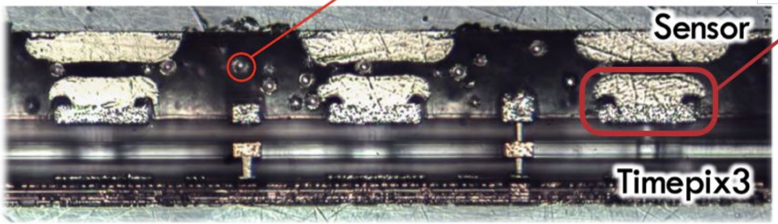


- Proof-of-principle for alternative in-house bonding technique using Anisotropic Conductive Film (ACF)
- Also used for module integration (see part from Florian)

Flip-chip bonder at UniGE

https://agenda.linearcollider.org/event/9211/contributions/49469/attachments/37464/58685/ILCX_MVicente_ACF.pdf

Conductive ACF ball



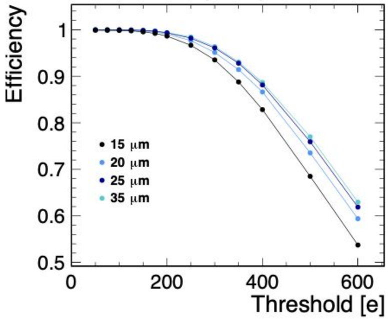
ENIG metallisation

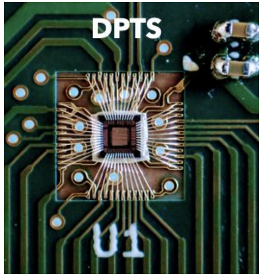
DT Micro-Pattern Technologies lab

Monolithic sensors in 65nm CMOS

- Process optimisation using simulations
- Characterisation of digital test-chip (DPTS) with Caribou DAQ
- Detailed test-beam studies spring next year
  - Timing performance + comparison to simulation

3D TCAD + Allpix Squared





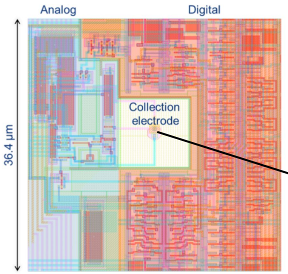
Katharina Dort [DT-TP]

CMOS pixel detector R&D and module development

Florian Dachs, Abhishek Sharma, Julian Weick, Peter Svihra, Mateus Vicente, Milou van Rijnbach, Dominik Dannheim, Petra Riedler*

EP-DT & WP 1.3 & EP-ADE in close collaboration with the QARTlab and Bondlab at the DSF, working closely CERN services and with institutes (e.g. Univ. of Geneva)

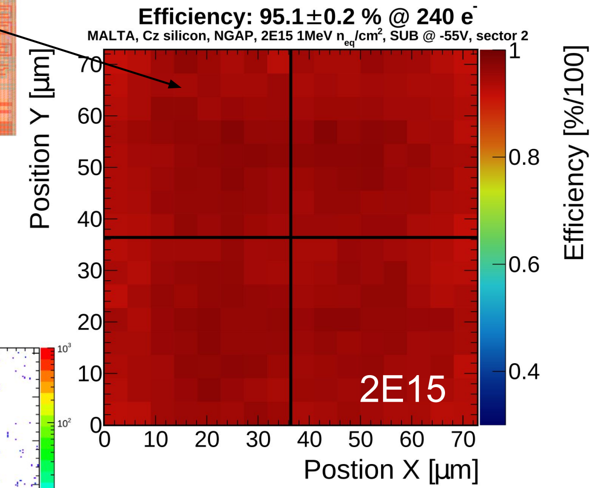
- Studies performed on the **monolithic CMOS pixel chip "MALTA" designed for high radiation hardness and produced in the 180 nm TowerJazz process**
    - 2x2 cm^2 overall size, 36.4 µm symmetric pixel pitch
    - fast detection and readout compatible with 40MHz event rate
    - redundant CMOS transceivers for chip-to-chip data and allows direct chip-to-chip powering
- Focus on the study of various **interconnection techniques and chip-to-chip transmission of power and data** to build large scale, low-mass modules
- **Optimize base wafer material,** chips produced on different epi wafers as well as on high res CZ wafers
- **Performance tests and qualification on chip and module level**



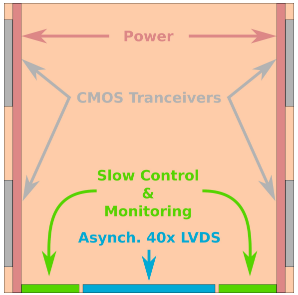
MALTA pixel cell

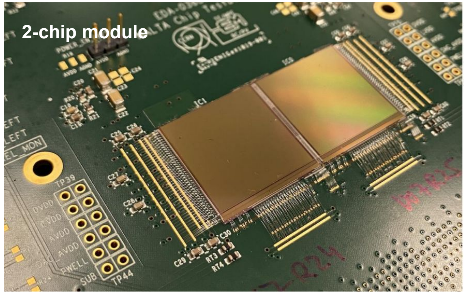
Efficiency: 95.1±0.2 % @ 240 e^-

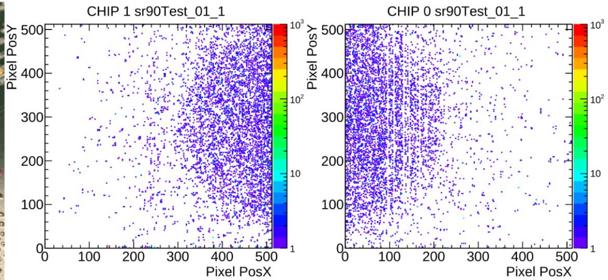
MALTA, Cz silicon, NGAP, 2E15 1MeV n_{eq}/cm^2, SUB @ -55V, sector 2



MALTA connectivity





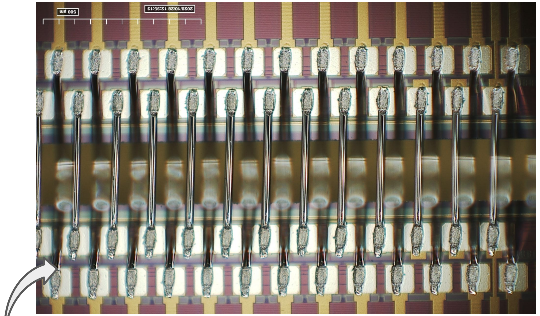


2-chip module, source scan

CMOS pixel detector R&D and module development

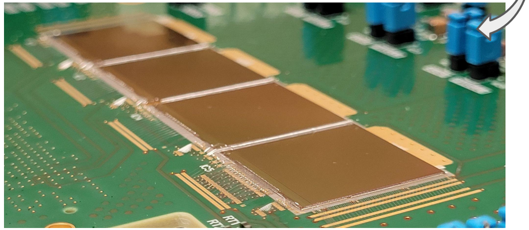
Study interconnection techniques and establish assembly procedures

wire bonds

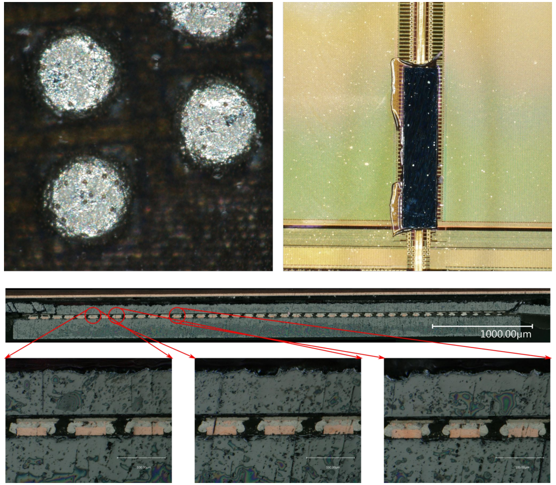


Al wedge wire bonding as baseline to study chip performance

Functioning 2-chip and 4-chip modules assembled and currently undergoing testing

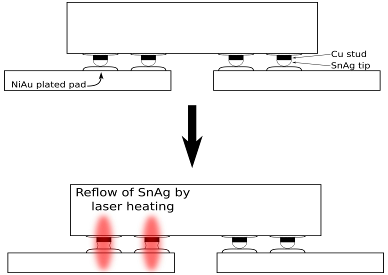


ACF



- ACF connections studies on **chip interconnection with a Silicon bridge**
- multiple glues tested
- multiple mech. supports developed

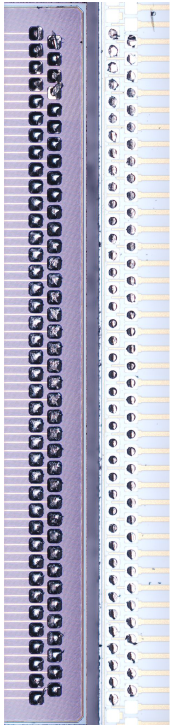
laser reflow



Laser reflow technique where Sn tipped Cu studs are bonded to Ni/Au plated pads

ENIG plating done by DT Micro-Pattern Technologies lab (Rui de Oliveira)

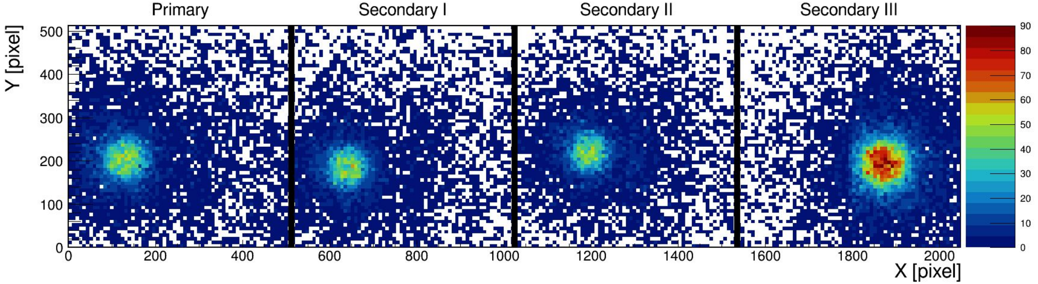
Technique shows high quality bonds on broken assemblies



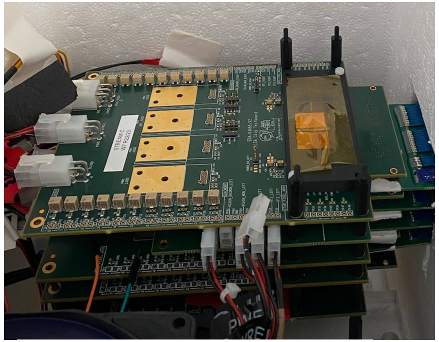
CMOS pixel detector R&D and module development

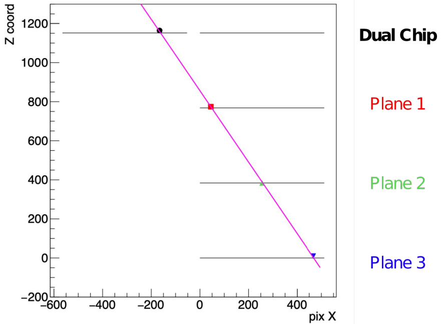
Study chip-to-chip power and data transfer - performance tests on 2-chip and 4-chip modules

Source scan on continuously read out **4-chip module** (total size 8x2 cm^2)
Readout full module via one chip only:



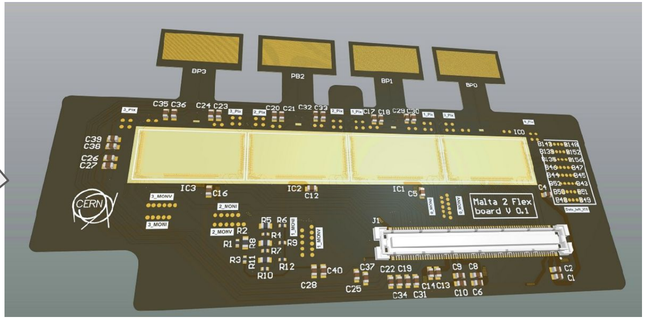
2-chip board in cosmic telescope:





- Tracking across gap in 2-chip modules and **efficiency studies ongoing**!
- Planning for test-beam measurements in 2022

Studies on current 4-chip board enable development towards light-weight flex-based 4-chip module



- **Chip-2-flex mounting**
- Designed for direct pad-to-pad bonding with **various interconnection techniques!**
- Design completed

Radiation Hard Silicon Detectors

Work performed by the EP-DT Solid State Detectors (SSD) team

Frameworks: RD50 EP R&D AIDA innova CMS

SSD: 1.5 Staff,
2 Fellows, 3 PhD students
& visiting scientists + collaborators
SSD labs in bldgs. 28 and 186

RD50 – Radiation hard semiconductor devices for very high luminosity colliders

⇒ 66 Institutes with 420 members, collaboration formed in 2001

⇒ CERN SSD acting as host lab, providing co-spokesperson, the budget holder and admin support (Veronique Wedlake)

⇒ CERN SSD scientific contributions in 4 main areas

Timing detectors for harsh radiation environments

in particular: LGAD – Low Gain Avalanche Diodes

Defect formation in defect engineered semiconductors

in particular: acceptor removal

Modelling of radiation damage on microscopic and device level

in particular: NIEL – Non Ionizing Energy Loss

Characterization tools for irradiated silicon devices

in particular: TPA-TCT - Two Photon Absorption - Transient Current Technique

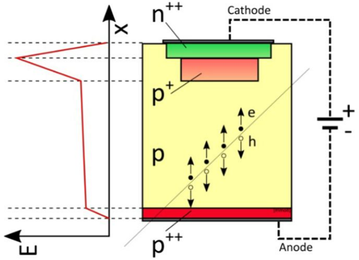
RD50 Workshop, Valencia, 17-19 November 2021

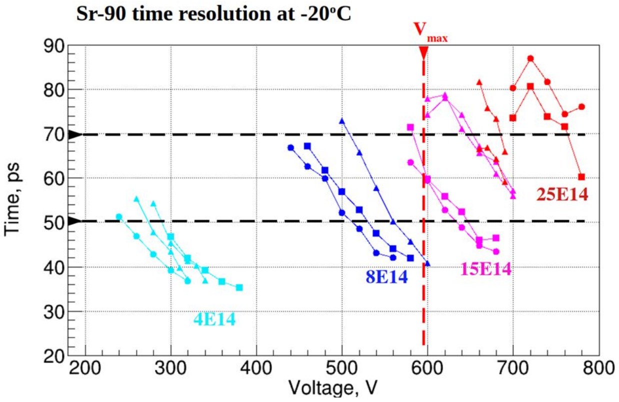
Radiation Hard Silicon Detectors

Example on Sensor Development:

LGAD – Low Gain Avalanche Diodes

operation after
high radiation levels
HPK prototype
sensors
for ETL/HGTD:





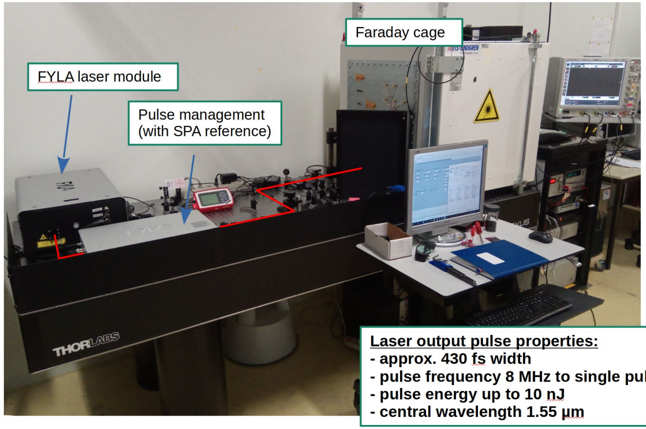
see: E.Curras, EP-RD seminar 06.12.21 (link)

Example on Characterization tools:

TPA-TCT: Two Photon Absorption – Transient Current Technique

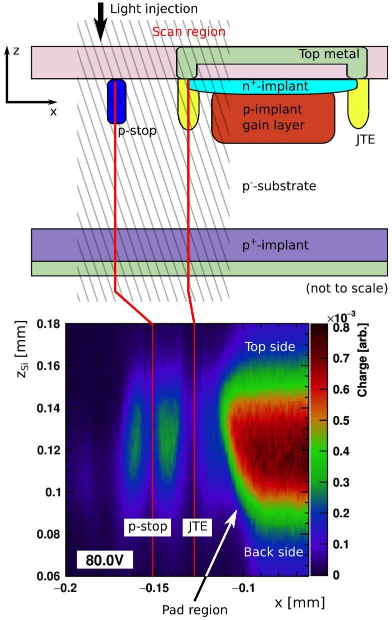
⇒ Laser induced charge generation in silicon devices used to evaluate detector properties (3D resolution: 1.5 um x 1.5 um x 15 um)

⇒ Hardware financed by a CERN Technology Transfer grant



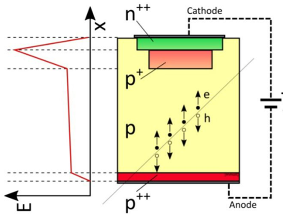
Laser output pulse properties:
- **approx. 430 fs width**
- **pulse frequency 8 MHz to single pulse**
- **pulse energy up to 10 nJ**
- **central wavelength 1.55 µm**

see: S.Pape, RD50 workshop Nov.2021 (link)

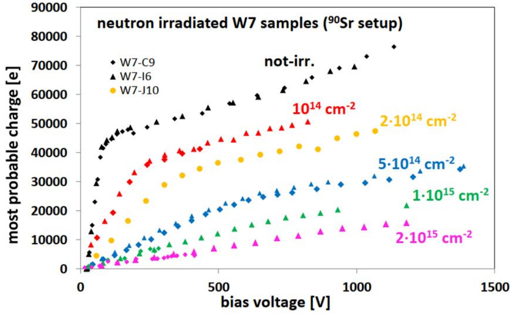


Radiation Hard Silicon Detectors

Radiation induced degradation of the LGAD gain:



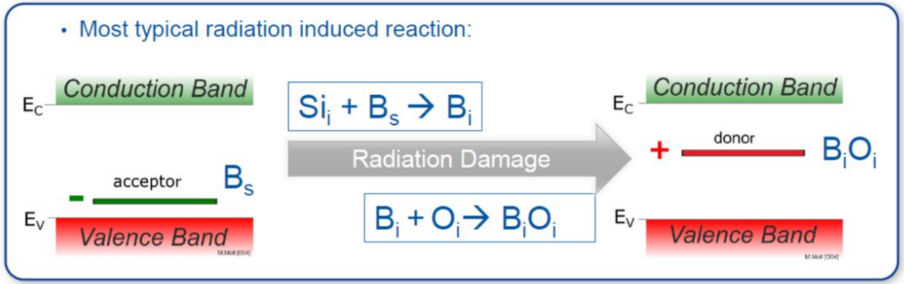
Moll, PoS(Vertex 2019) 027



Kramberger et al. 2015 JINST 10 P07006

Acceptor Removal Effect

⇒ Deactivation of Boron as shallow dopant



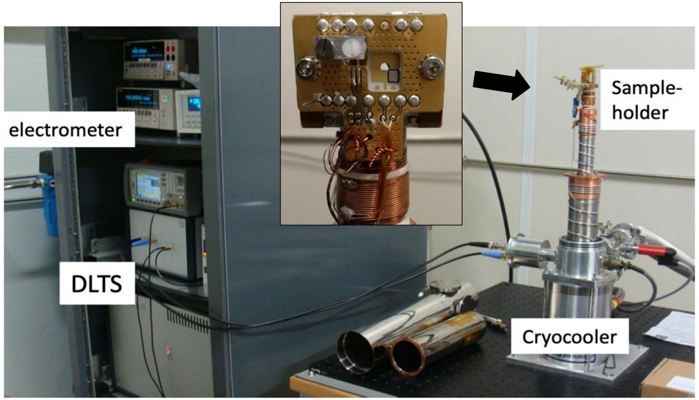
- Most typical radiation induced reaction:

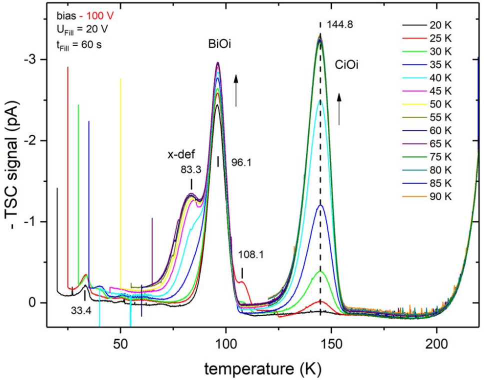
$Si_i + B_s \rightarrow B_i$

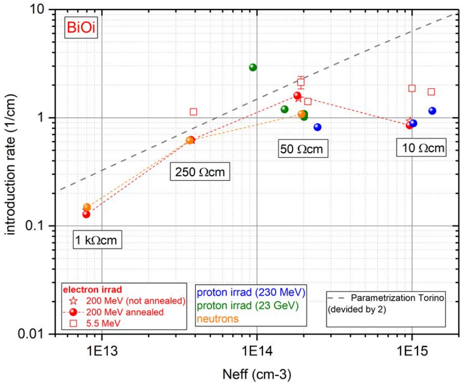
Radiation Damage

$B_i + O_i \rightarrow B_iO_i$

Defect spectroscopy: Deep-level-transient spectroscopy (DLTS) & Thermally stimulated current technique (TSC)







A. Himmerlich et al. RD50 workshop 2021