Karlsruhe Institute of Technology

Discussion on HPK Sensor Qualification

On behalf of the CMS Tracker Sensor Working Group

INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK

Overview

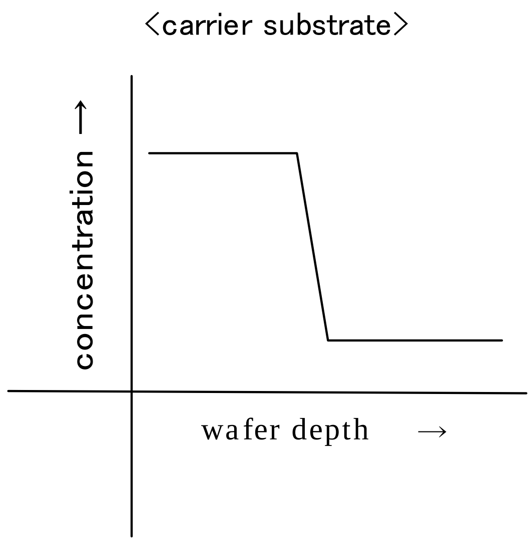
- Deep backside diffusion on thin sensors
  - Measurements and implications
- General backside process
  - Optical properties
- Measurement results
  - IV comparison
  - Strip measurements
- Questions on process details
- Short introduction to further techniques we use

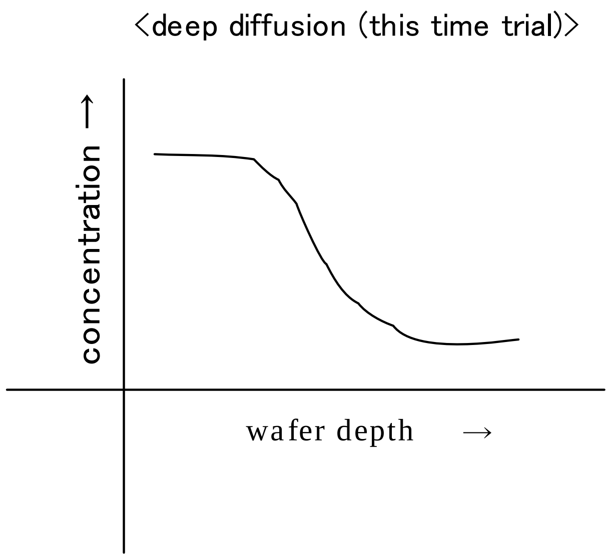
Deep backside diffusion on thin sensors

A. Dierlamm
Institut für Experimentelle Kernphysik

Deep backside diffusion

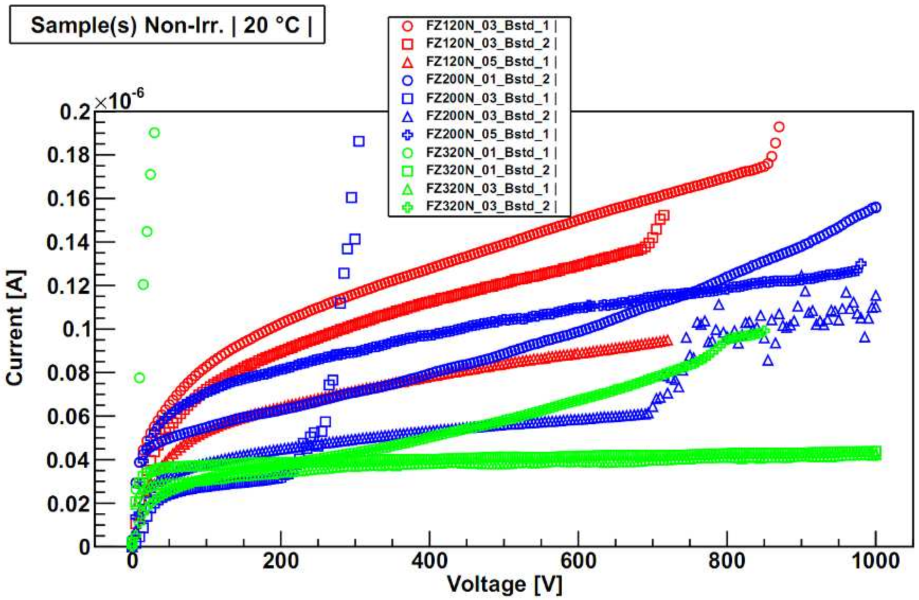
- According to your reply you used a deep backside diffusion to reduce the active thickness of the sensors
- You say that this is cheaper than wafer bonding. What is the difference in costs?
- If process proves to be reliable it would be a very interesting alternative
- Having expected sensors on carrier substrate this caused several surprises to us which I will go through…



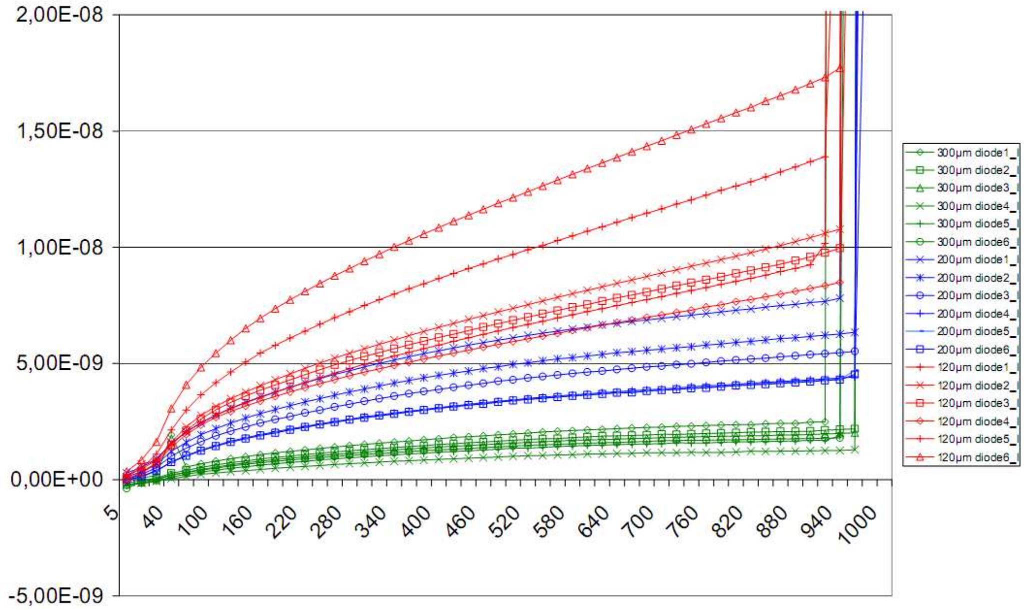


Non-saturating IV on thin sensors

- IV does not saturate like for 320µm sensors
- Thin sensors draw higher current (still very low)
  - Thermal stress from diffusion process?
  - Shallower doping profile allows leaking of diffusion layer into depleted volume?
- Unusual spread of currents on same wafer

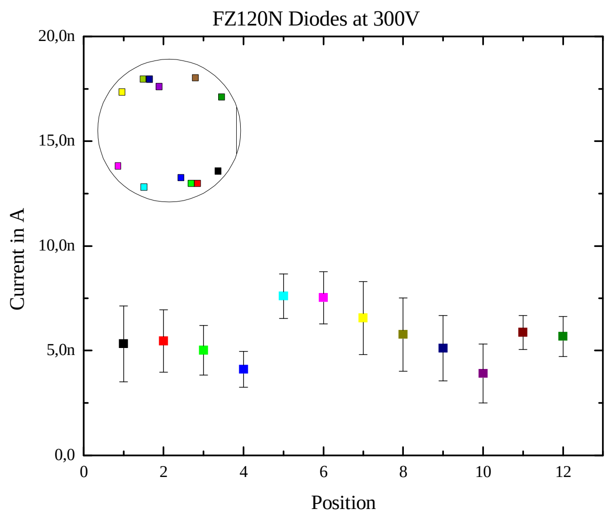


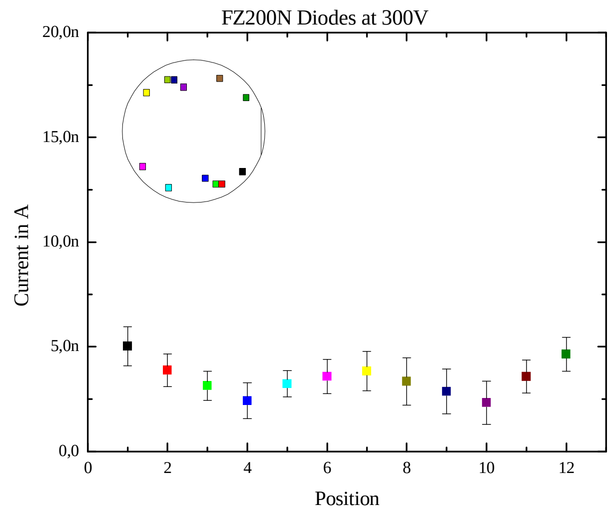
Baby_std @ KIT

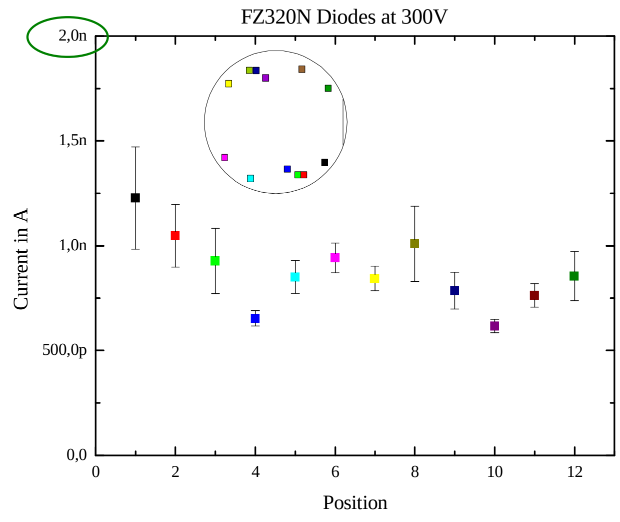


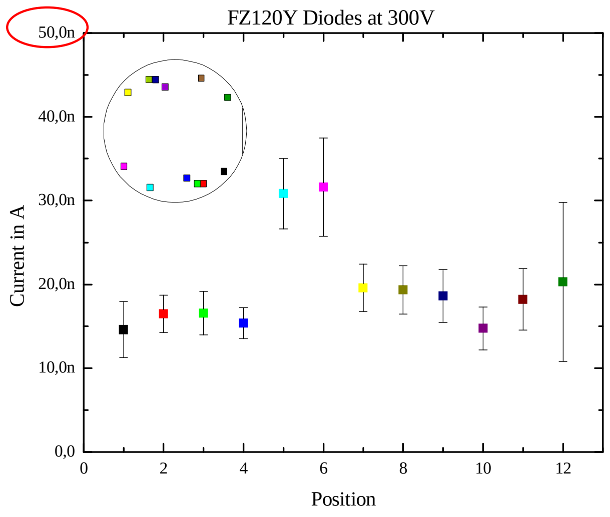
Diodes @ HPK

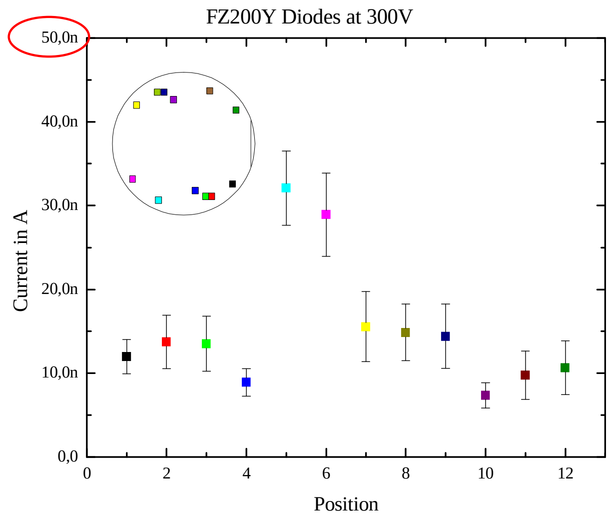
Regional variation (Current at 300V, HPK data)

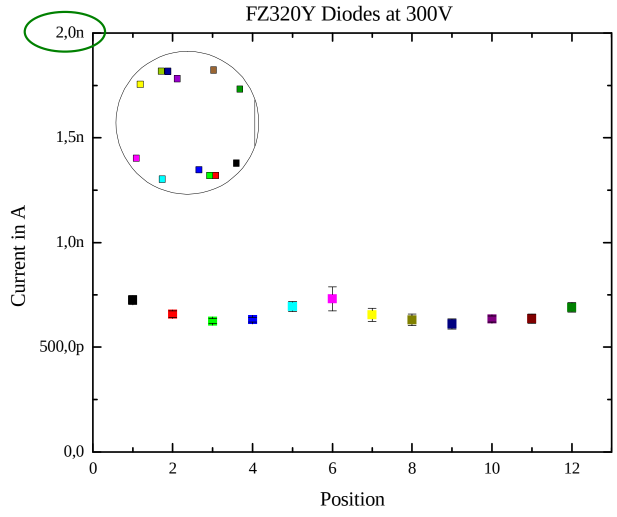








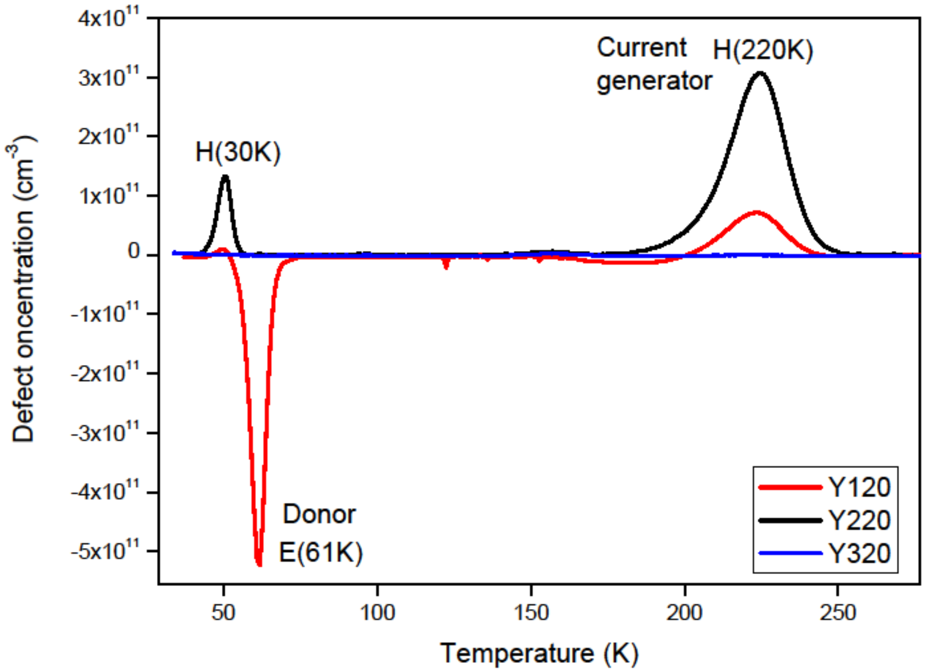


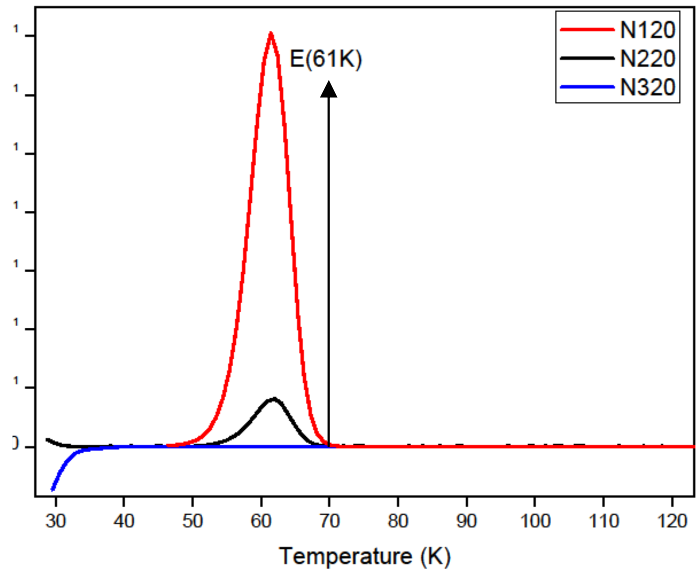


Bulk defects due to deep diffusion

Method: Deep Level Transient Spectroscopy

from A. Junkes, UHH





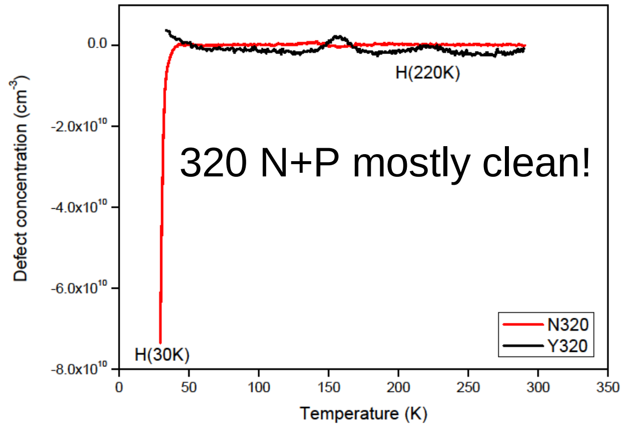
Defect increases with deeper diffusion (Measurements possible to 170 μm depth)

Important defects found in all thin FZ materials:

E(61K): Donor, increase of pos. SC

H(220K): Current generator

Reason for defect creation: deep diffusion



Donor E(61K) influences N_{eff}

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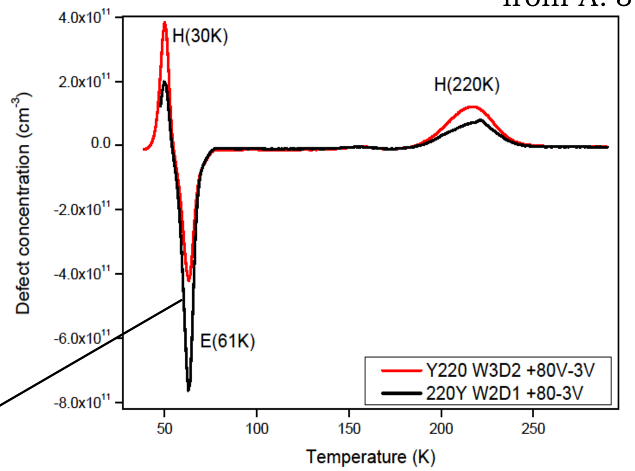
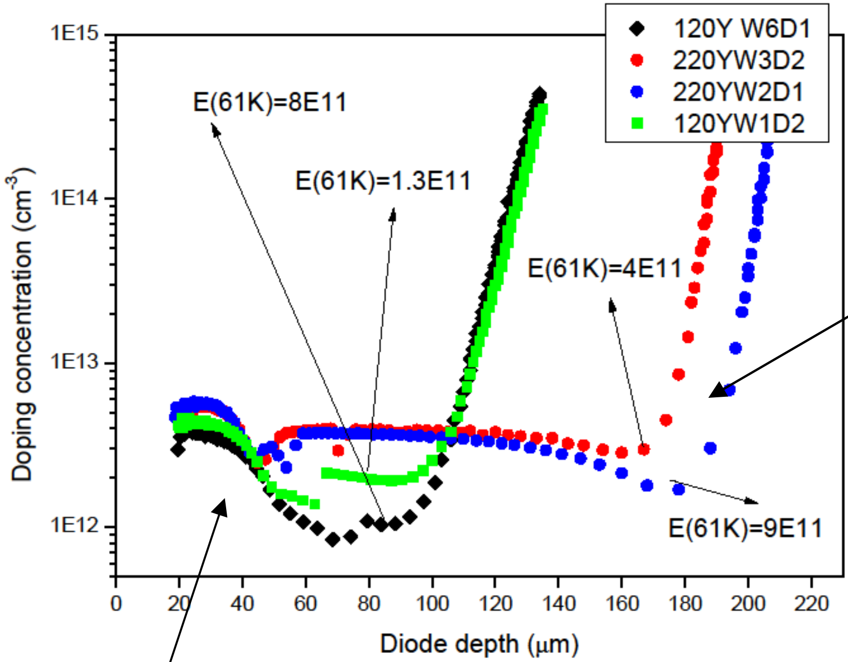
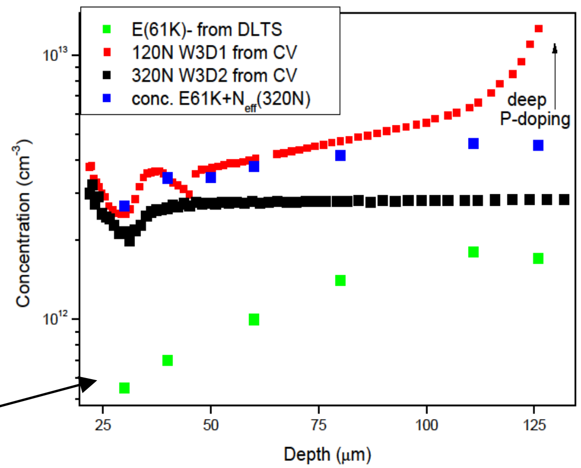
from A. Junkes, UHH







E(61K) reduces N_{eff} in p-type

E(61K) increases N_{eff} in n-type

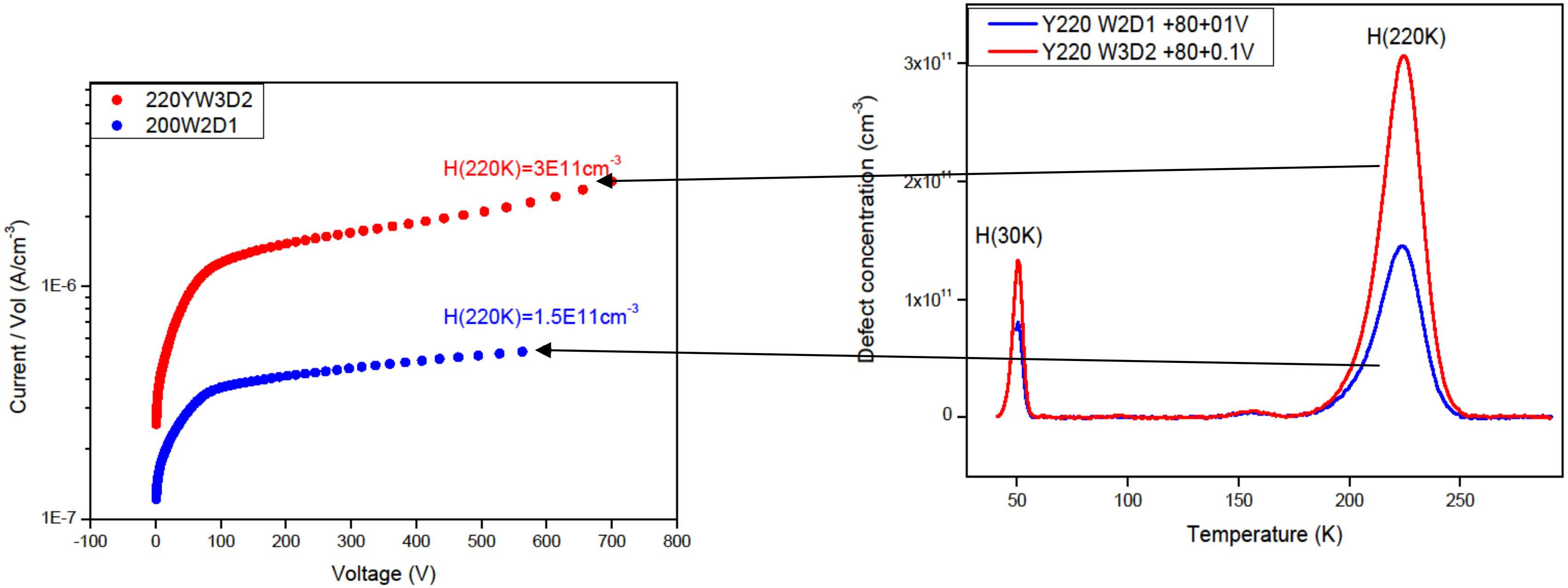
E(61K)- concentration per depth added to N_{eff} of „clean“ N320 reproduces N_{eff} of N120

Depth profile of E(61K) reveals increase towards interface

Defect predicts real N_{eff} of N120

H(220K): deep current generator

from A. Junkes, UHH

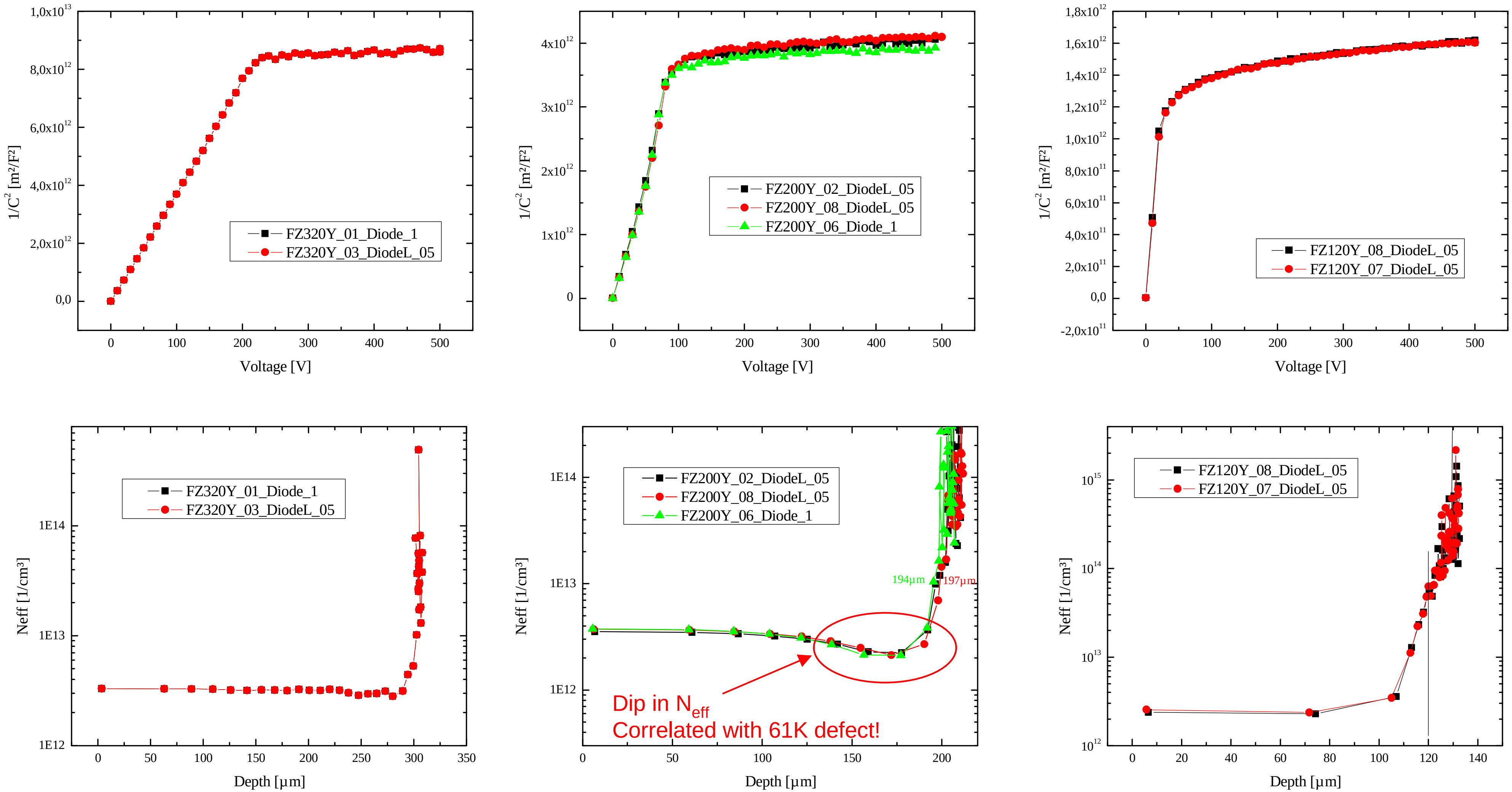


•Shallow defects can not produce current but H(220)

•Defect concentration scales with current generation

Extended junction for thin sensors

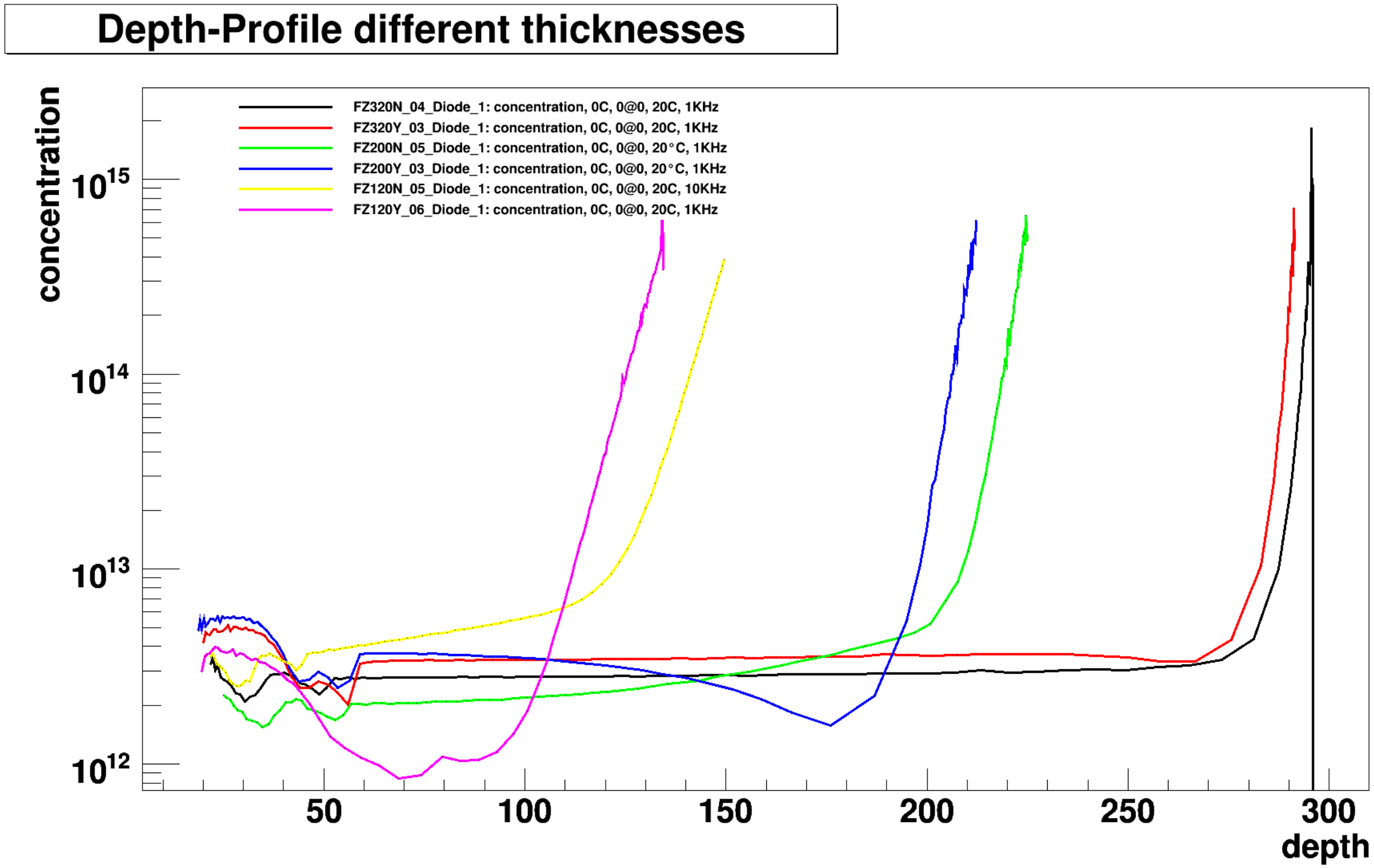
FZ320Y FZ200Y FZ120Y



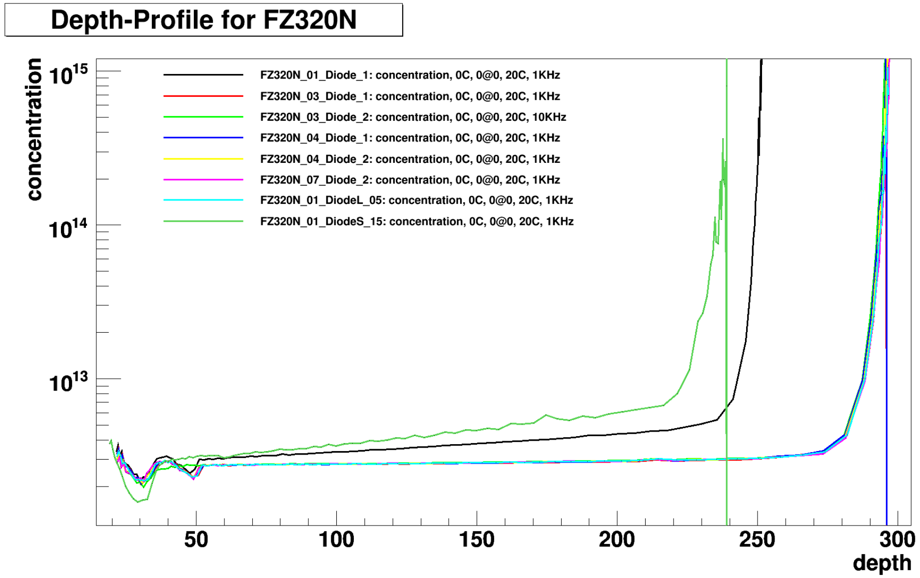
This makes it difficult to extract precisely the full depletion voltage when analyzing the behavior under irradiation

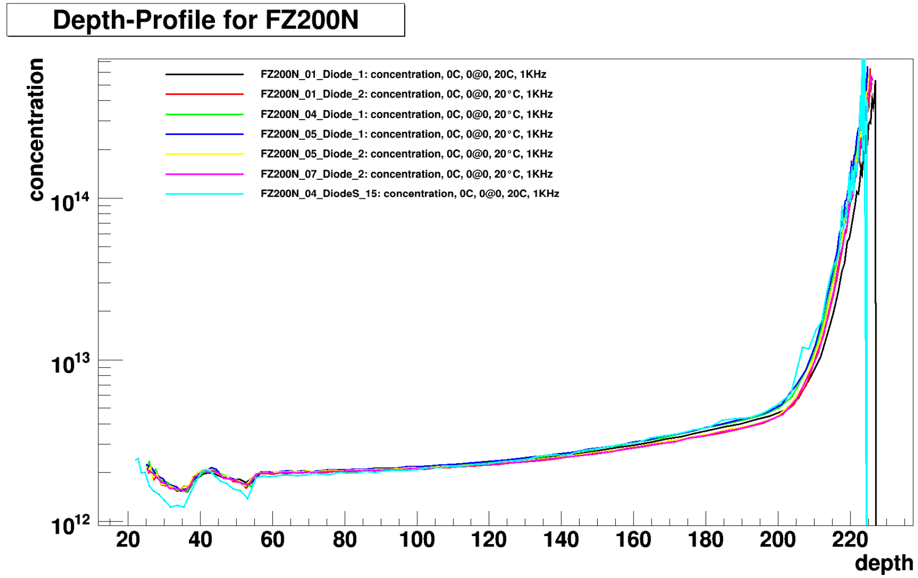
Active thickness

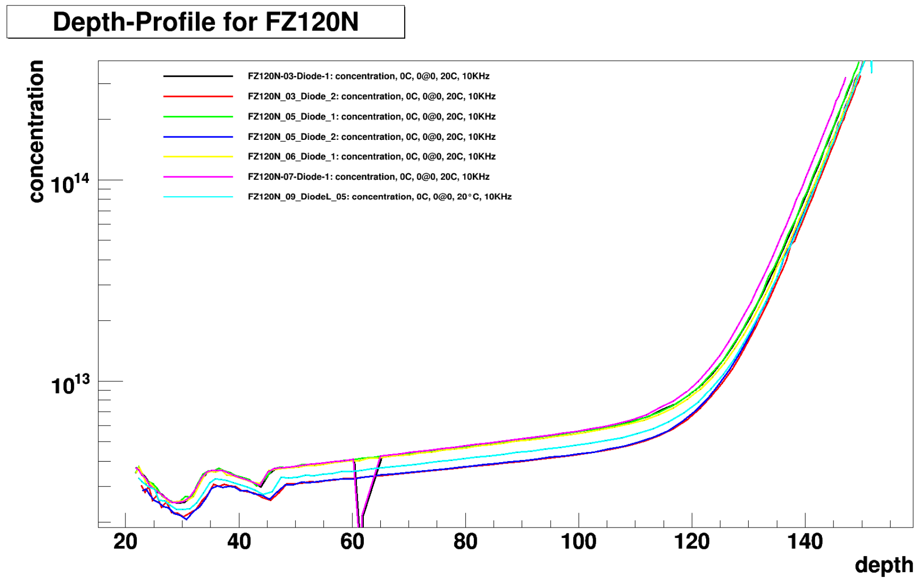
- In general, p-type sensors are thinner by 5-20µm
- p-type sensors have minimum in N_{eff} just before the junction



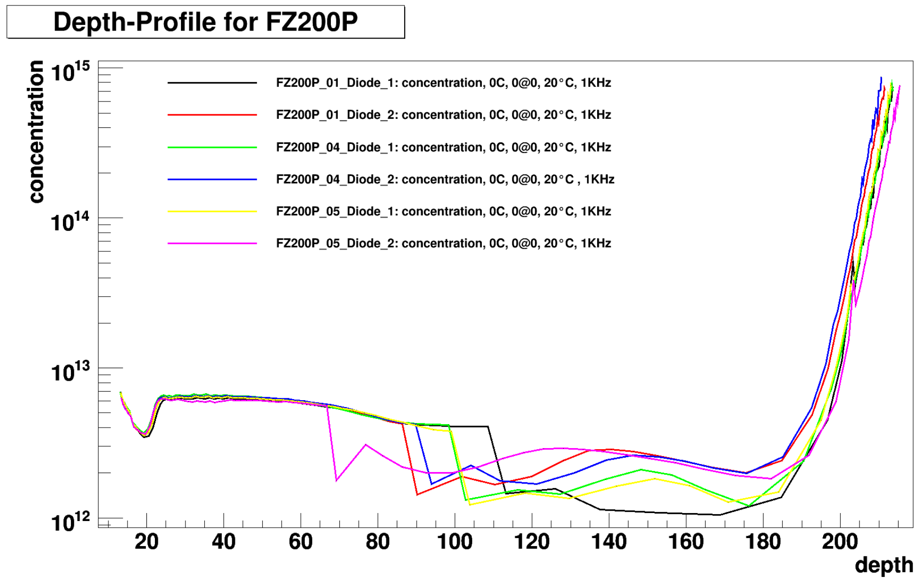
N-type

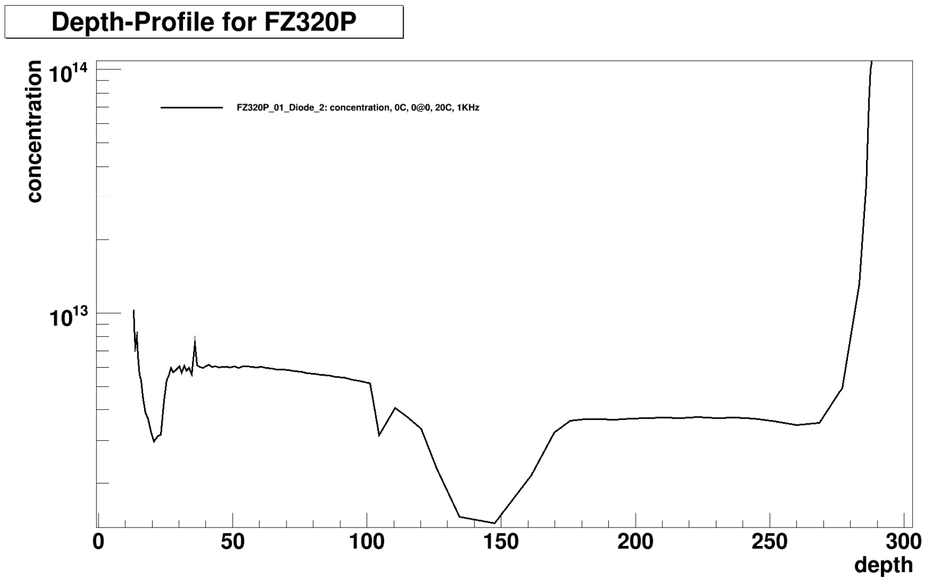

Depth-Profile for FZ320N
FZ320N_01_Diode_1: concentration, 0C, 0@0, 20C, 1KHz
FZ320N_03_Diode_1: concentration, 0C, 0@0, 20C, 1KHz
FZ320N_03_Diode_2: concentration, 0C, 0@0, 20C, 10KHz
FZ320N_04_Diode_1: concentration, 0C, 0@0, 20C, 1KHz
FZ320N_04_Diode_2: concentration, 0C, 0@0, 20C, 1KHz
FZ320N_07_Diode_2: concentration, 0C, 0@0, 20C, 1KHz
FZ320N_01_DiodeL_05: concentration, 0C, 0@0, 20C, 1KHz
FZ320N_01_DiodeS_15: concentration, 0C, 0@0, 20C, 1KHz
concentration
10^{15}
10^{14}
10^{13}
50
100
150
200
250
300
depth

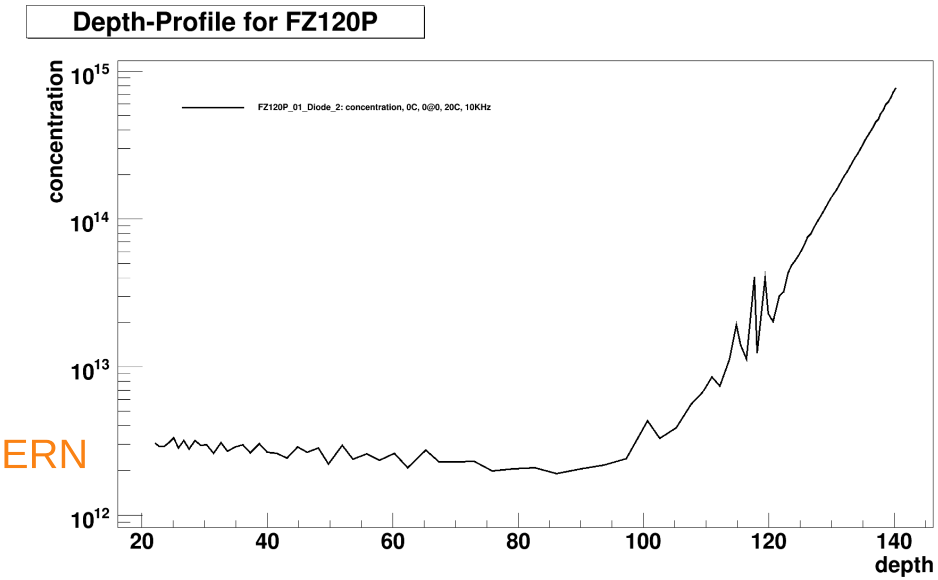

Depth-Profile for FZ200N
FZ200N_01_Diode_1: concentration, 0C, 0@0, 20C, 1KHz
FZ200N_01_Diode_2: concentration, 0C, 0@0, 20°C, 1KHz
FZ200N_04_Diode_1: concentration, 0C, 0@0, 20°C, 1KHz
FZ200N_05_Diode_1: concentration, 0C, 0@0, 20°C, 1KHz
FZ200N_05_Diode_2: concentration, 0C, 0@0, 20°C, 1KHz
FZ200N_07_Diode_2: concentration, 0C, 0@0, 20°C, 1KHz
FZ200N_04_DiodeS_15: concentration, 0C, 0@0, 20C, 1KHz
concentration
10^{14}
10^{13}
10^{12}
20
40
60
80
100
120
140
160
180
200
220
depth


Depth-Profile for FZ120N
FZ120N-03-Diode-1: concentration, 0C, 0@0, 20C, 10KHz
FZ120N_03_Diode_2: concentration, 0C, 0@0, 20C, 10KHz
FZ120N_05_Diode_1: concentration, 0C, 0@0, 20C, 10KHz
FZ120N_05_Diode_2: concentration, 0C, 0@0, 20C, 10KHz
FZ120N_06_Diode_1: concentration, 0C, 0@0, 20C, 10KHz
FZ120N-07-Diode-1: concentration, 0C, 0@0, 20C, 10KHz
FZ120N_09_DiodeL_05: concentration, 0C, 0@0, 20°C, 10KHz
concentration
10^{14}
10^{13}
20
40
60
80
100
120
140
depth

P-type





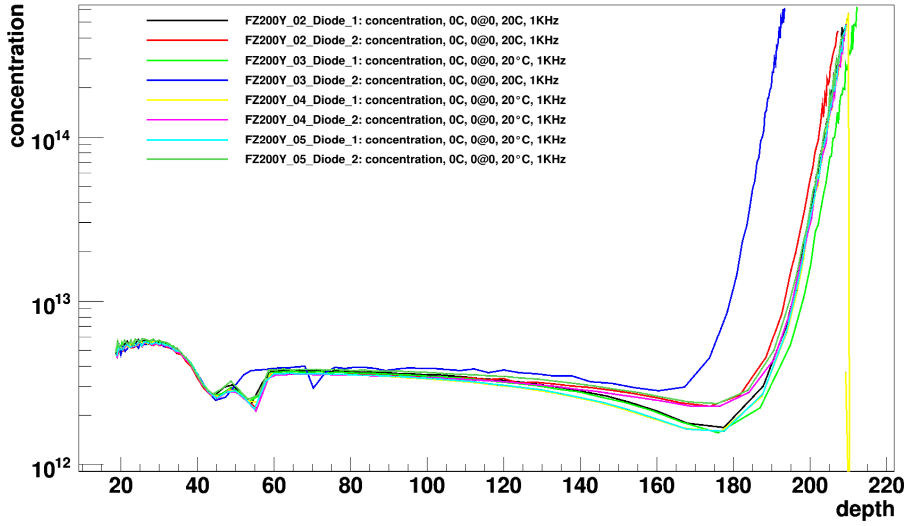


In addition:
FZ**320**P_W3_Diode1 was measured to be ~265µm at CERN

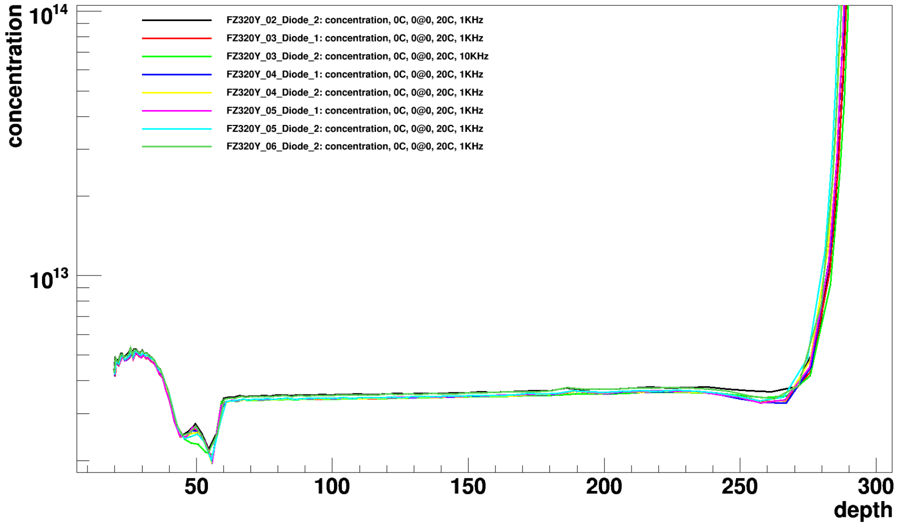
A. Dierlamm
Institut für Experimentelle Kernphysik

Y-type

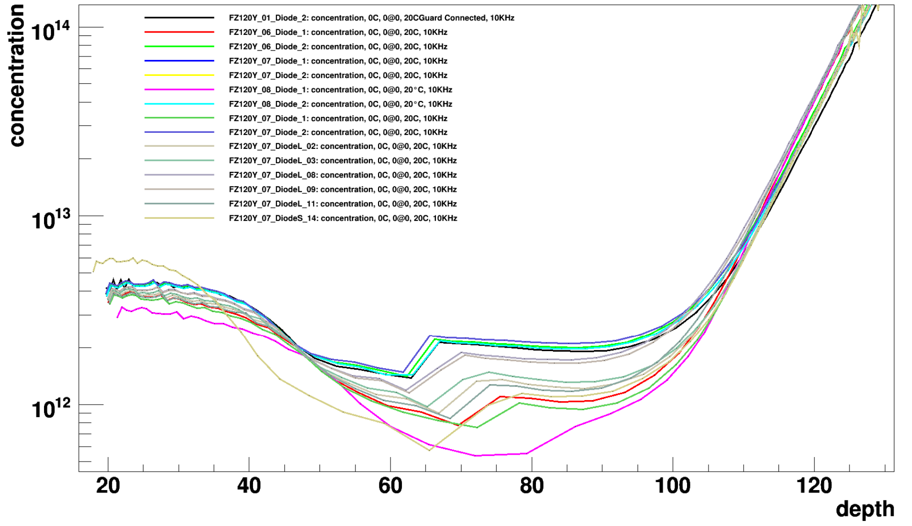
Depth-Profile for FZ200Y



Depth-Profile for FZ320Y

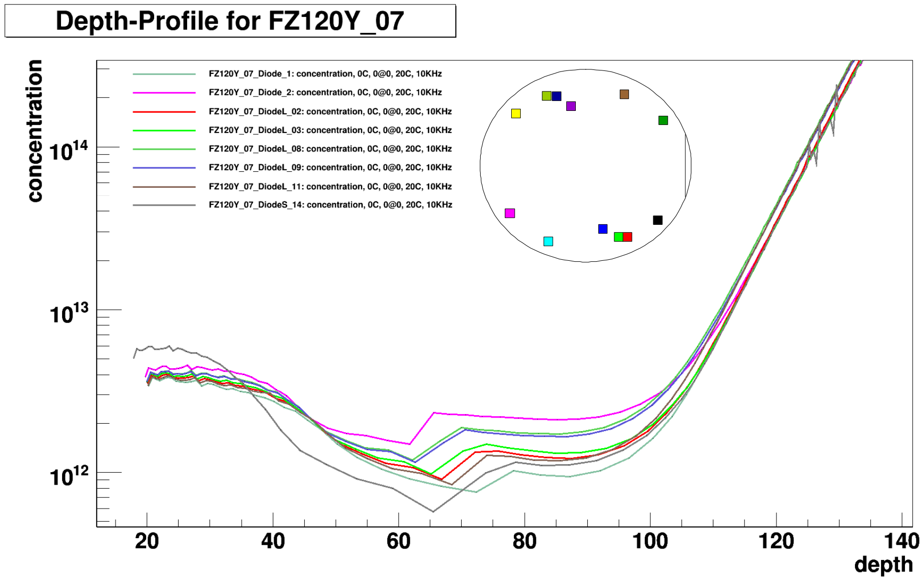


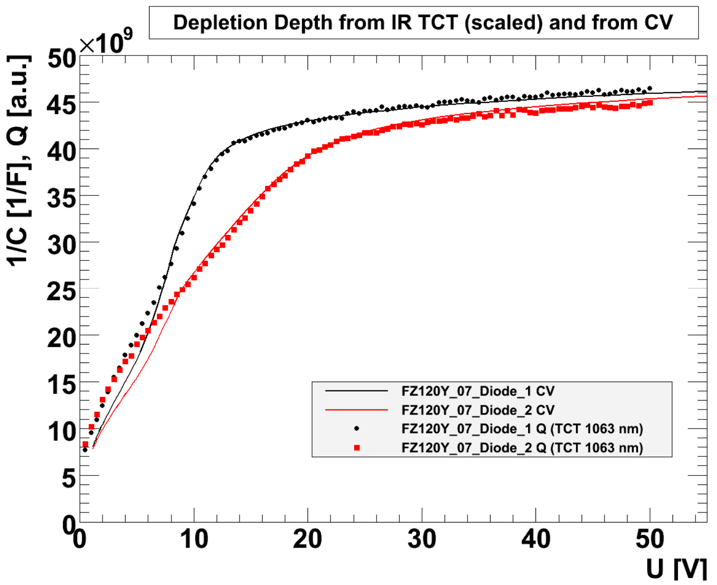
Depth-Profile for FZ120Y

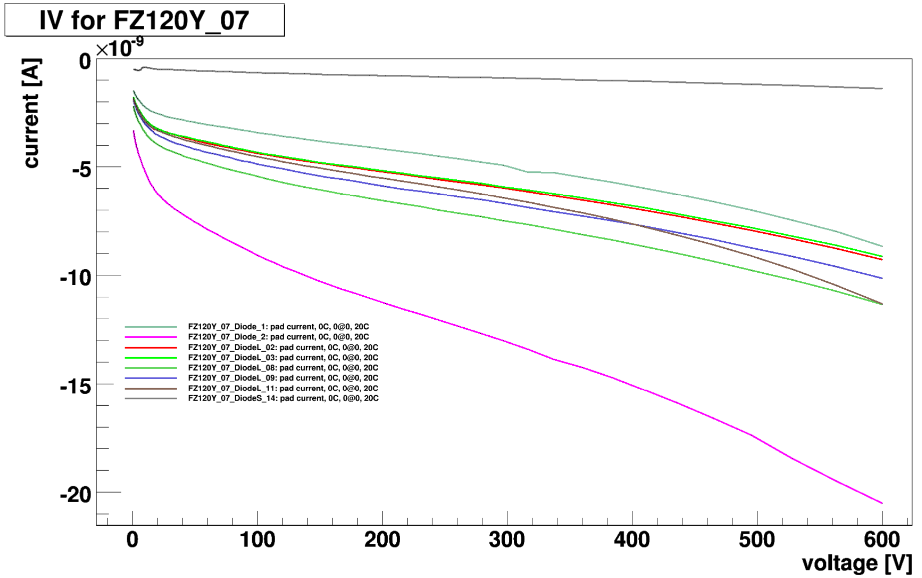


Differences in depletion behavior seen on one wafer

- FZ120Y, wafer 07
- Shape of CV confirmed by charge collection

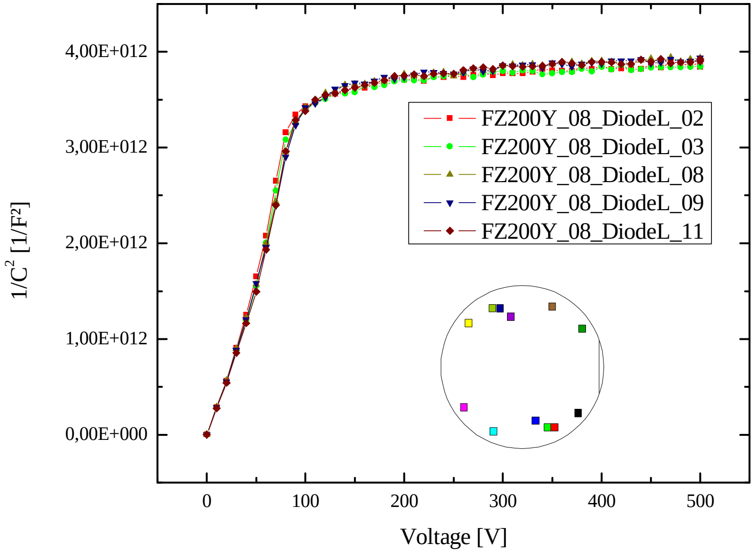


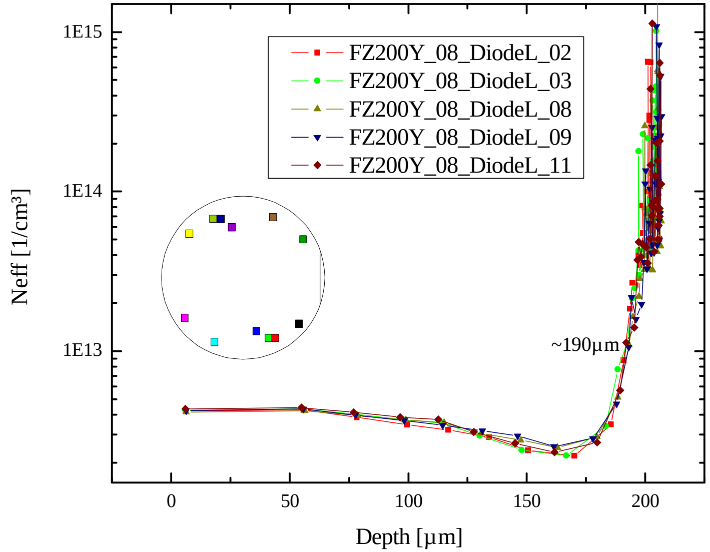


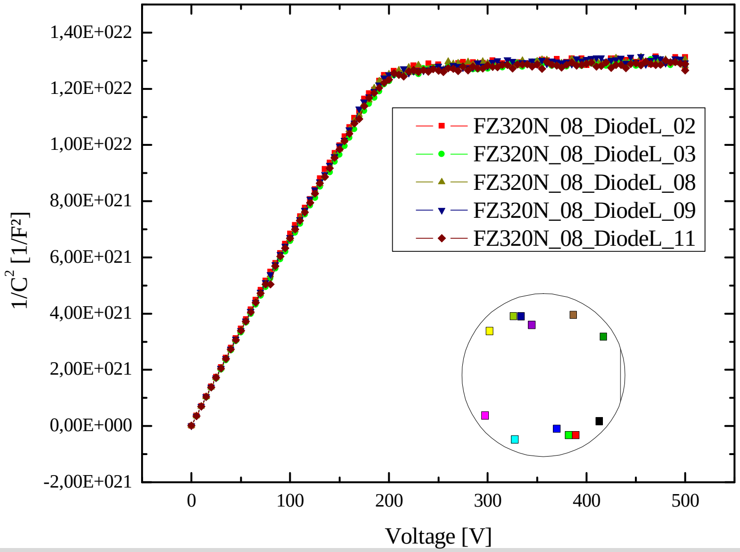


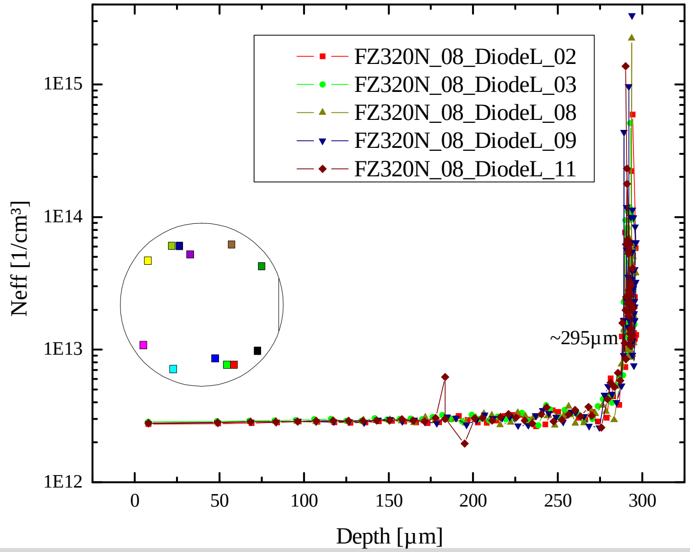
Depletion

- Other wafers show homogeneous distributrion









Summary - Deep Backside Diffusion

- Higher leakage current on thin material
  - Absolute value not critical, well below specs
  - If caused by strain, are there further implication?
- Defects found in thin material
  - Alarming; need to prove long-term stability
  - Will they form bad defects after irradiation?
- Broader interface between high resistive bulk and highly doped substrate
  - More difficult to extract full depletion voltage
  - More difficult to estimate collected charge
- Active thickness of sensors shows difference of p- and n-types
  - What is the difference in process?
- Few wafers show big difference in thickness
  - Need to understand origin
- On one wafer difference in depletion seen for different diodes
  - Process homogeneity?

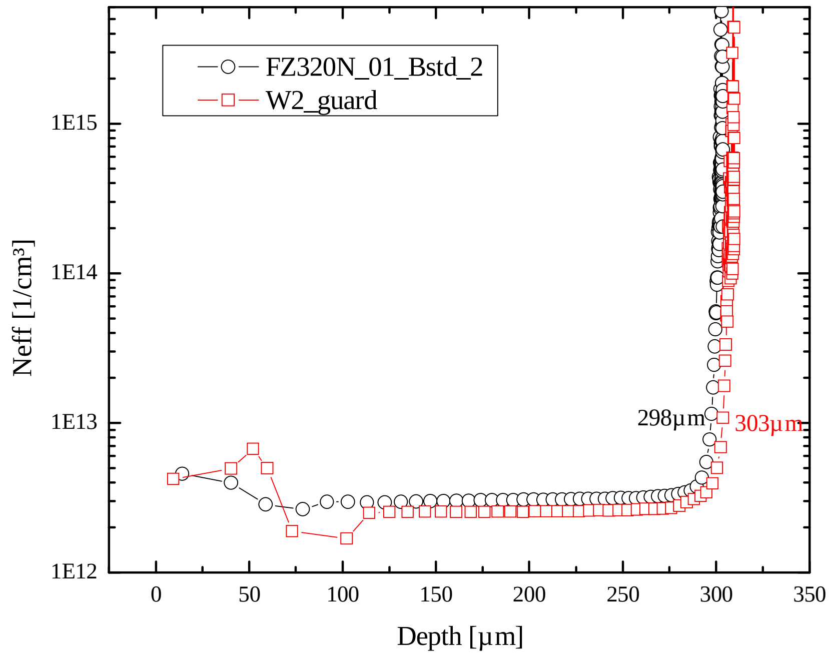
A. Dierlamm
Institut für Experimentelle Kernphysik

General backside process

A. Dierlamm
Institut für Experimentelle Kernphysik

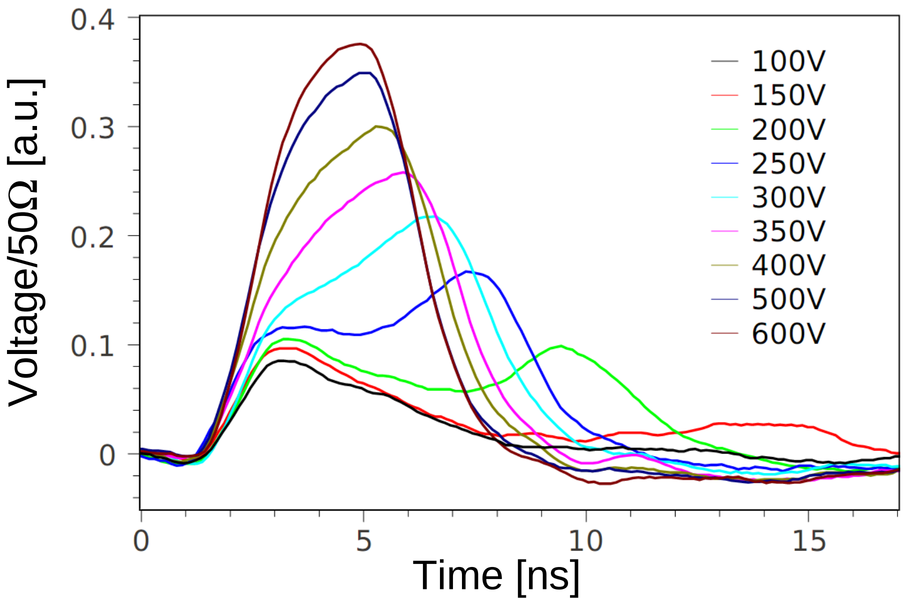
Comparison to old CMS production

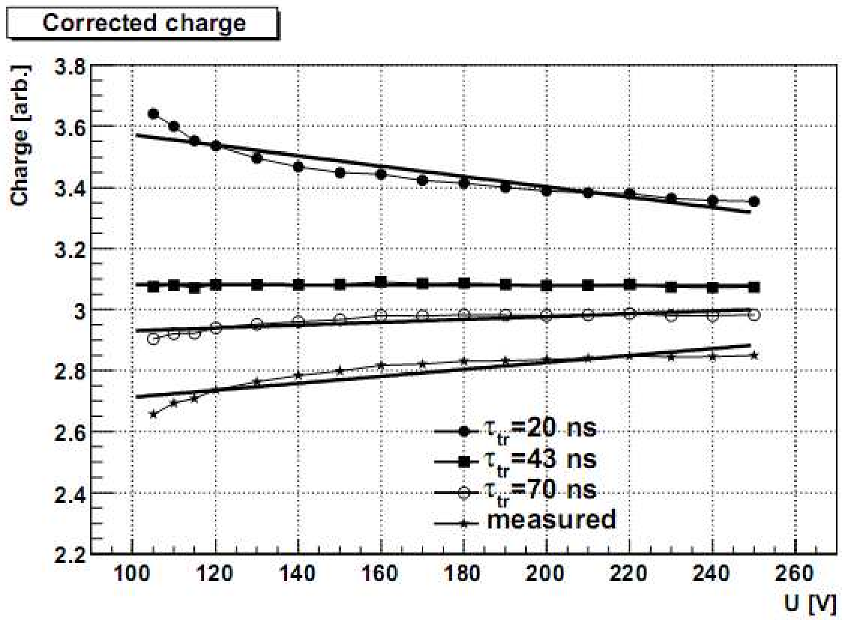
- We compare a Mini Sensor from the old production (type W2, 320µm) with the a new FZ320N
- Measurement of thickness from CV gives about same thickness
- Is implant depth of ~20µm a reasonable assumption?
- Is this a deep implantation or medium deep diffusion? Is this an in-house process?



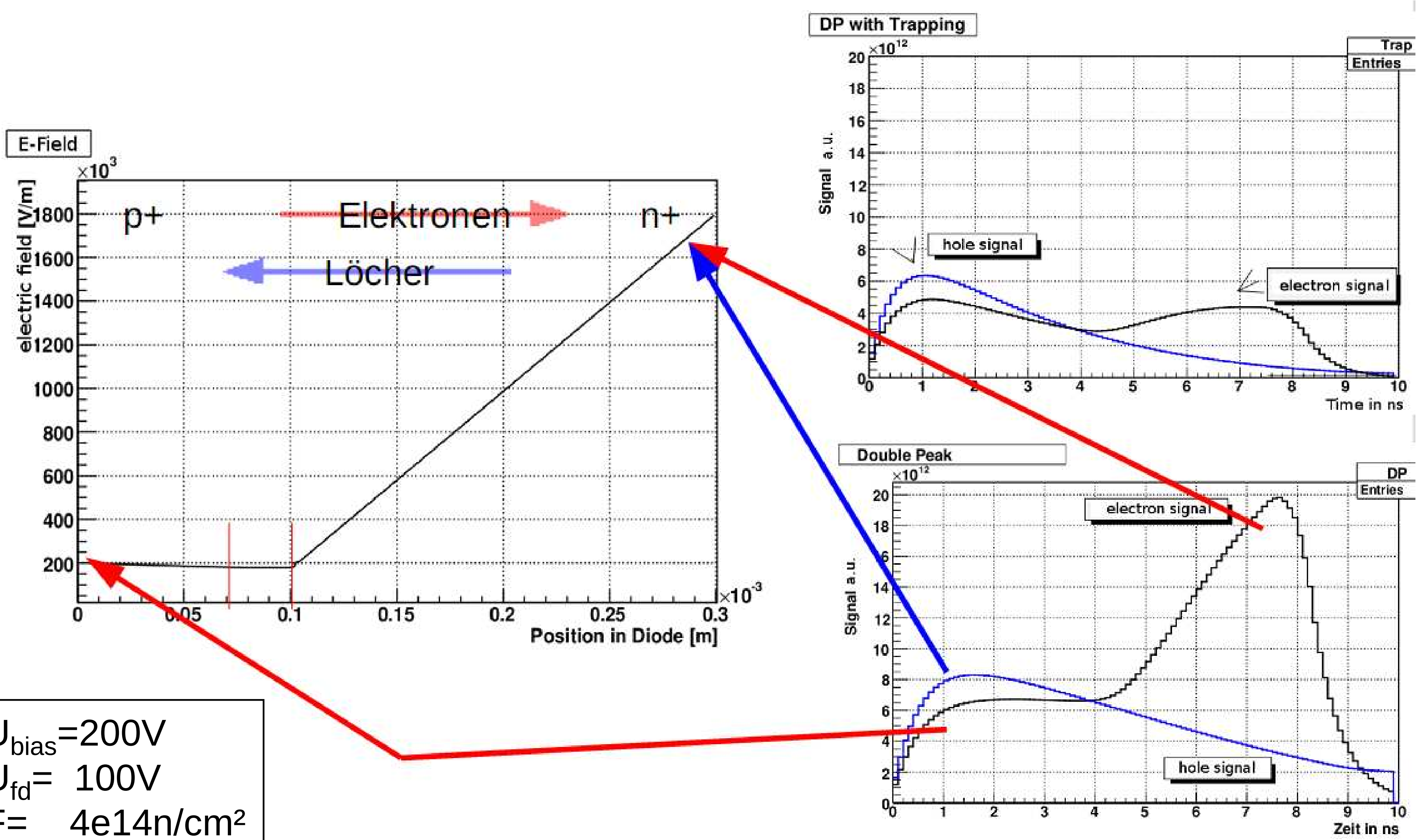
Transient Current Technique

- Short laser pulse with small penetration length generates charge carriers on one side of diode
- Current pulse reflects the carrier drift
- Signal generated on back provides drift information on charge carrier which is collected in sensors made from same material
- Due to trapping in irradiated material the later part of the current pulse is suppressed and we need information of **both** injections to reconstruct electric field
- In addition, the effective trapping time can be extracted from a collection of pulses at various bias voltages





Reconstruction of E-Field in n-MCz diode

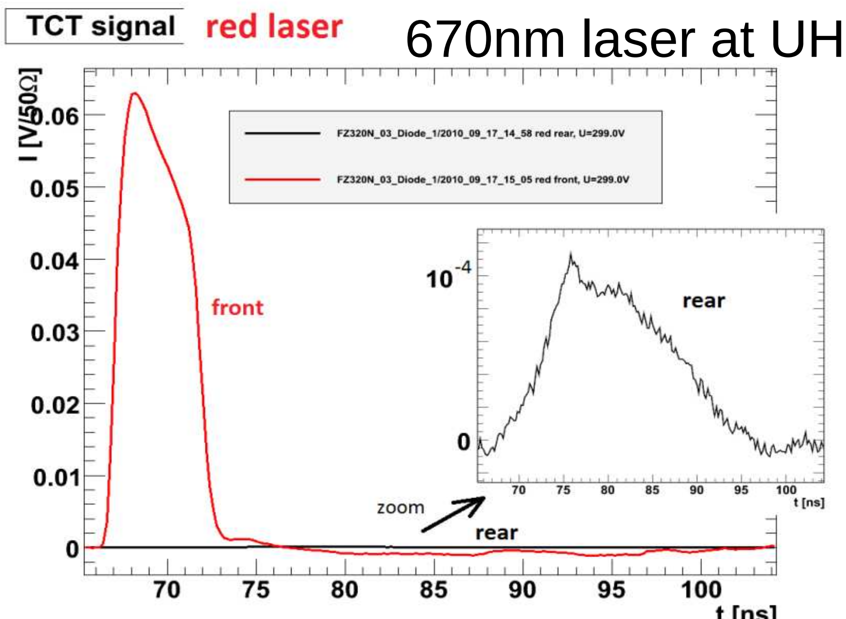


U_{bias}=200V
U_{fd}= 100V
F= 4e14n/cm²
T= -20℃

Red laser cannot penetrate from back

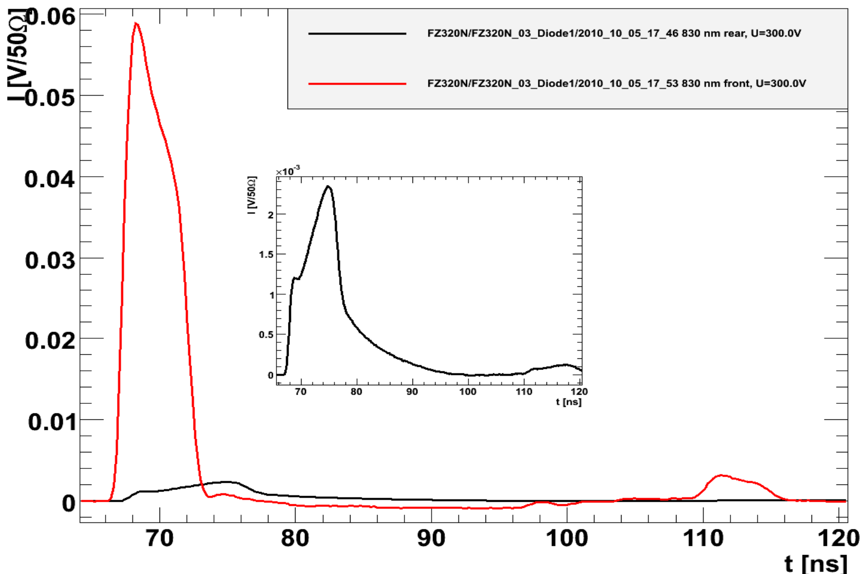
- Implantation of back side is too deep to generate enough charge in the active volume
- Long tail due to charge generation in implant
- Need to choose laser with longer wavelength
  - Generates deeper distribution of charge carriers including signal from opposite sign charge carrier
  - Evaluating optimal wavelength and impact on analysis…

670nm laser at UHH



from Th. Pöhlsen, UHH

830nm laser at UHH



from Th. Pöhlsen, UHH

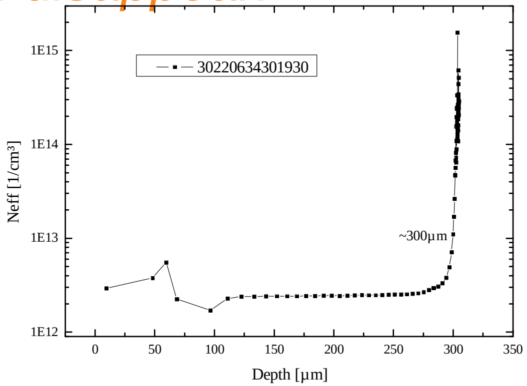
Old Production allowed signal generation from back-side!

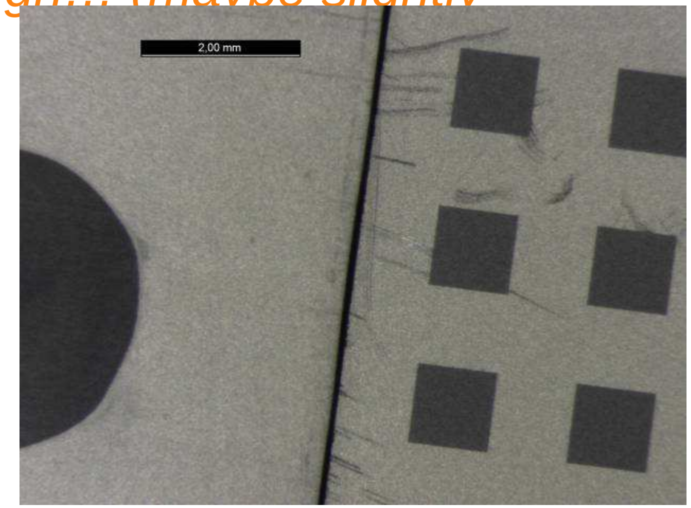
We are investigating this at the moment.
Red laser from back on old CMS-mini from HPK shows nice signal with APV read-out!!!
Random diode of old production did not show red laser signal from back!?!?
Now we check the diodes from the same wafer of the CMS mini…
Only a bit better than current production! Small distorted signal seen on diode.

Additional etching of current diode on back did not change behavior.

Etched back if working CMS mini looks similar though… (maybe slightly darker)

So this slide will disappear!



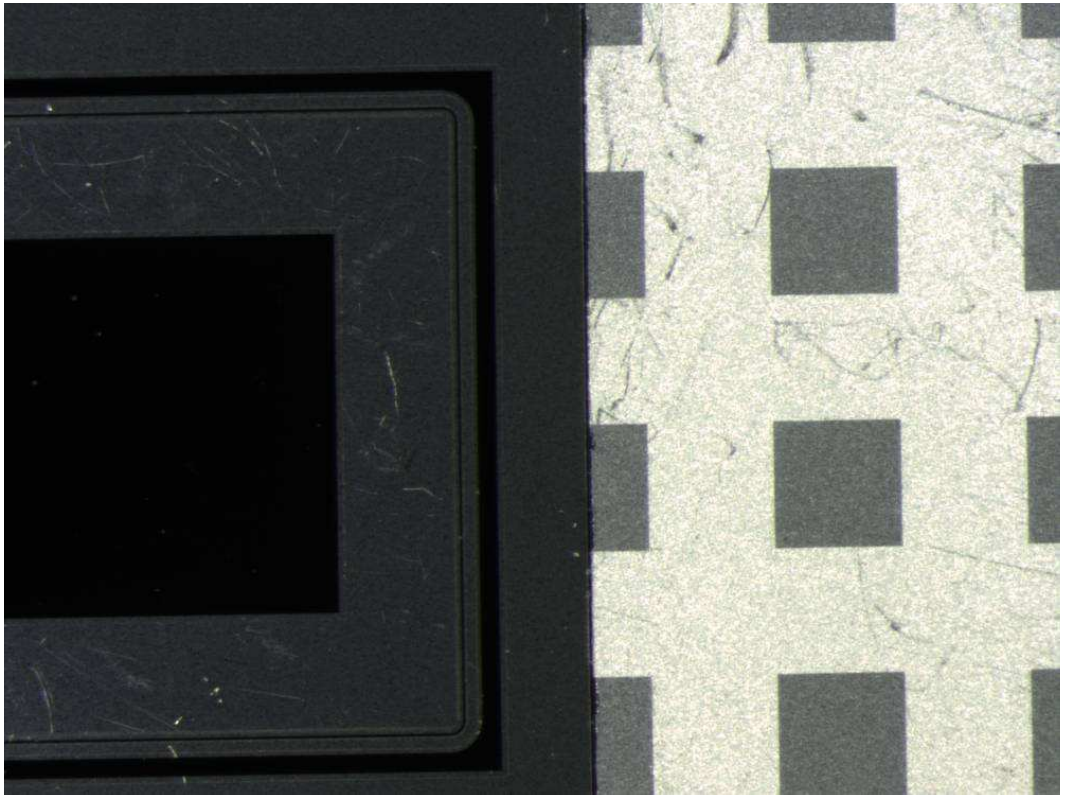


Etched old production

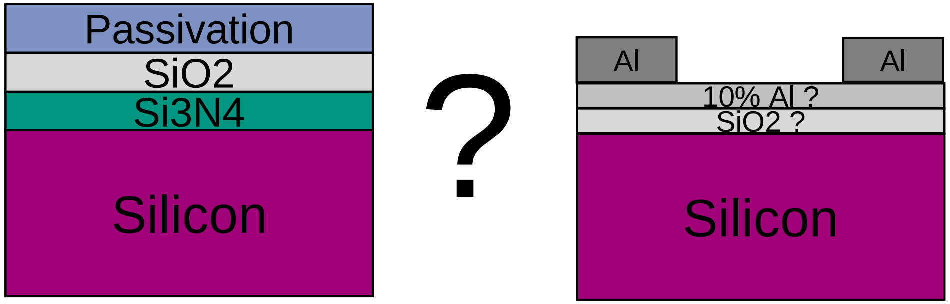
FZ320N

Loss of IR intensity from back

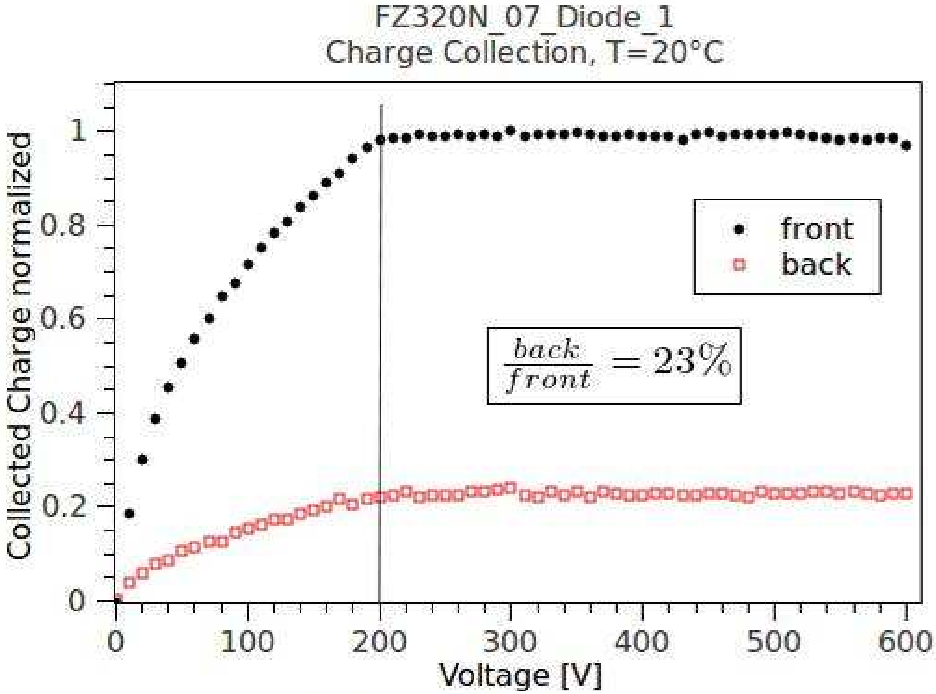
- Comparing generated charge by 1060nm laser light from front and back gives up to 94% loss from back
- p-type shows less charge from front and back
- Laser spot is ~200µm and positioned well within opening of back grid
- Laser from front hits opening on back (no signal variation when passing over grid opening)
- Optically quite different surface
- What are the surface layers on front and back?

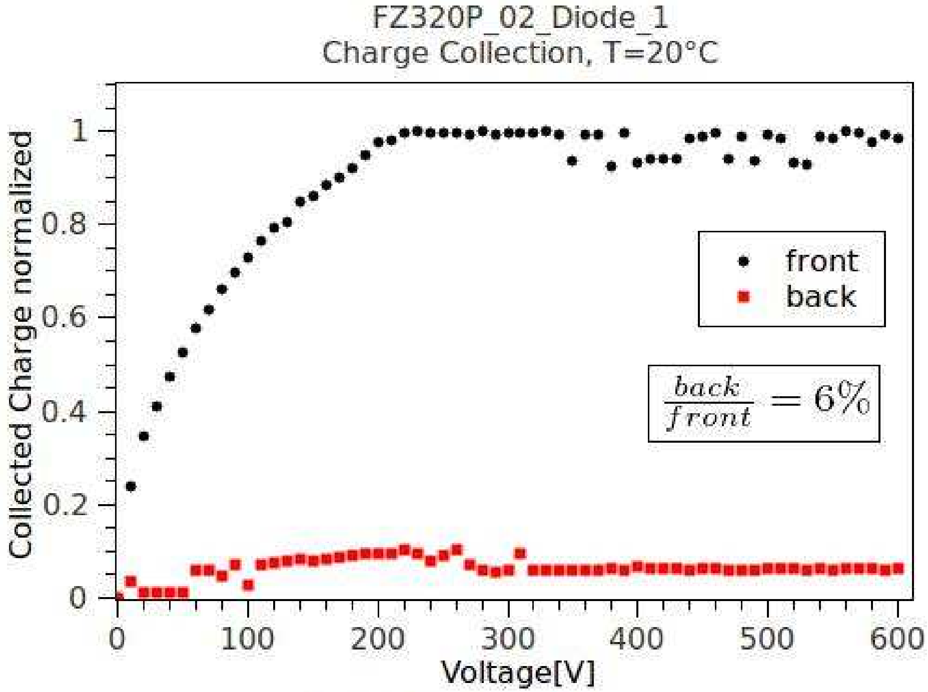


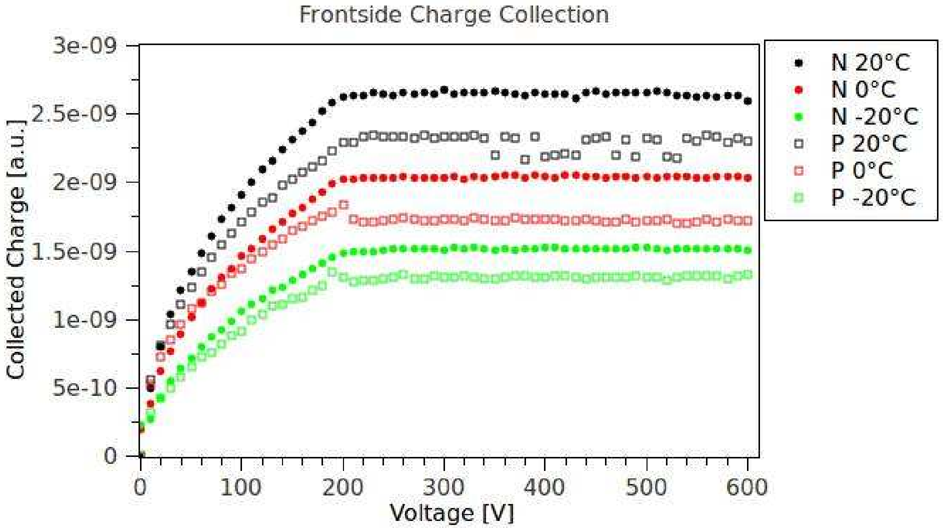
This is one single image with homogenous illumination and brightness setting

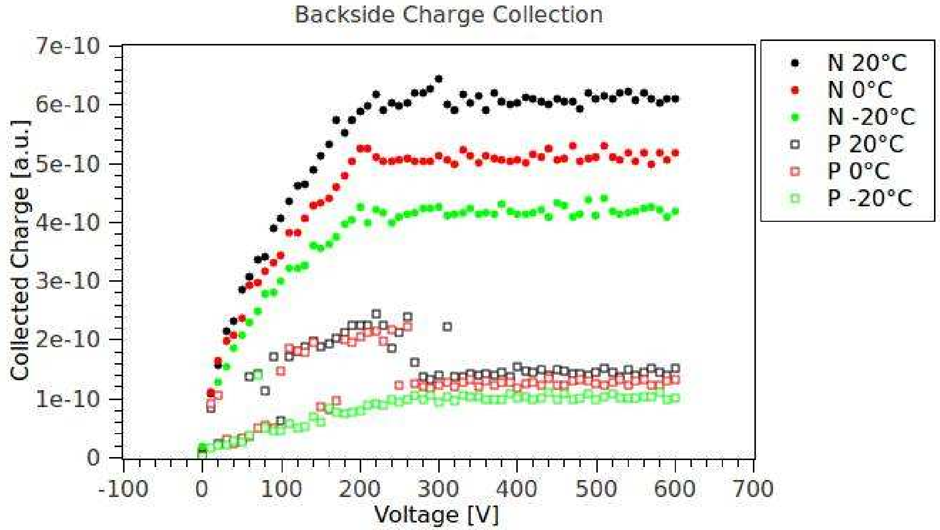


Collected charge with 1060nm laser









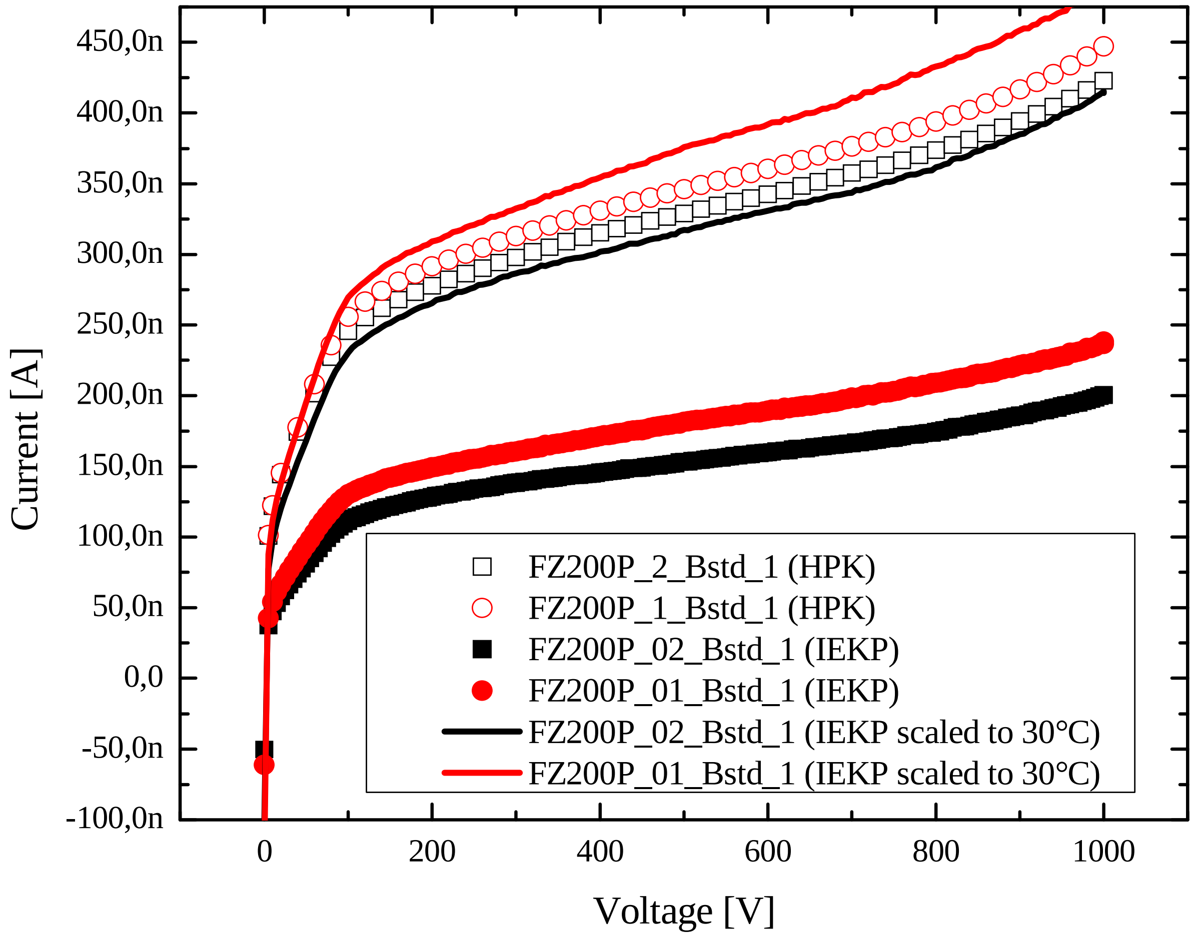
Summary – General Backside Process

- There is a >20µm highly doped layer on backside
  - Present in old CMS production
  - Does this improve HV stability?
  - Red laser cannot penetrate from backside; need to adjust wavelength, which reduces quality of analysis from TCT
  - We can study electric field and charge collection with a new tool even on thin devices: edge-TCT
- IR intensity is reduced when injecting from back
  - Not expected
  - Need to understand difference in process

Further Measurements

A. Dierlamm
Institut für Experimentelle Kernphysik

Comparing IV



Scaling (E_a=1.09eV) our measurements to 30℃ gives comparable results.
Under which conditions did HPK measure?

Strip measurements

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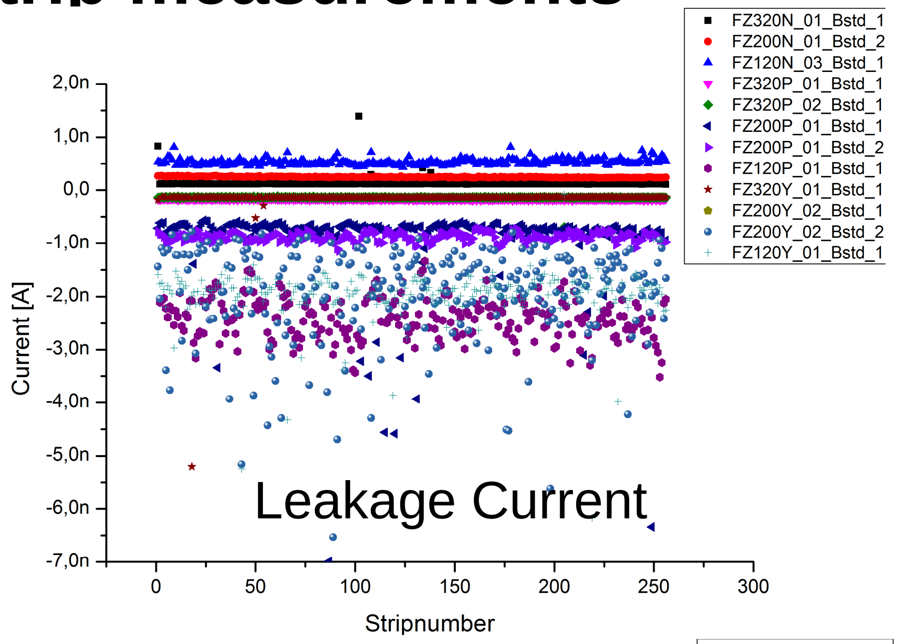
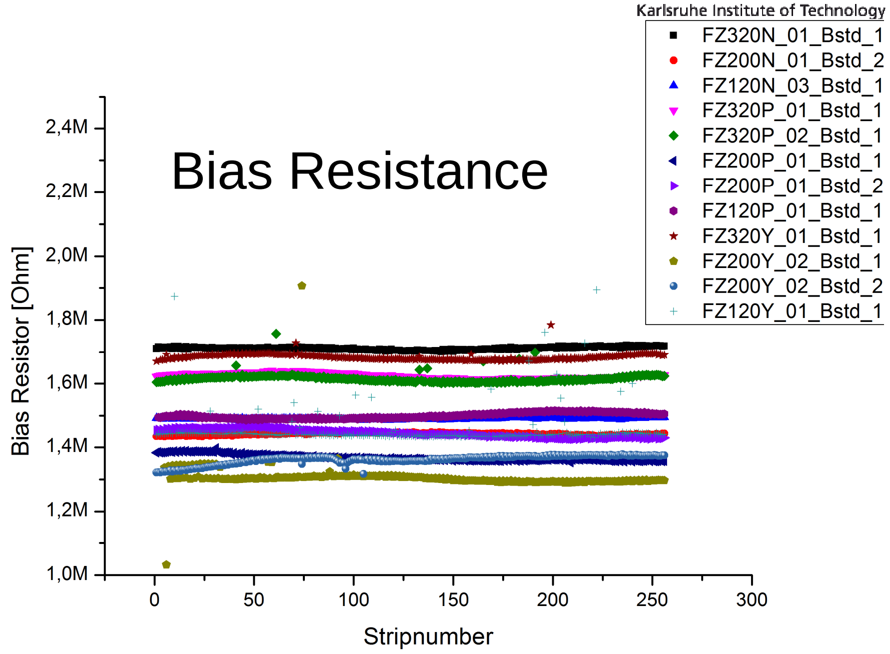
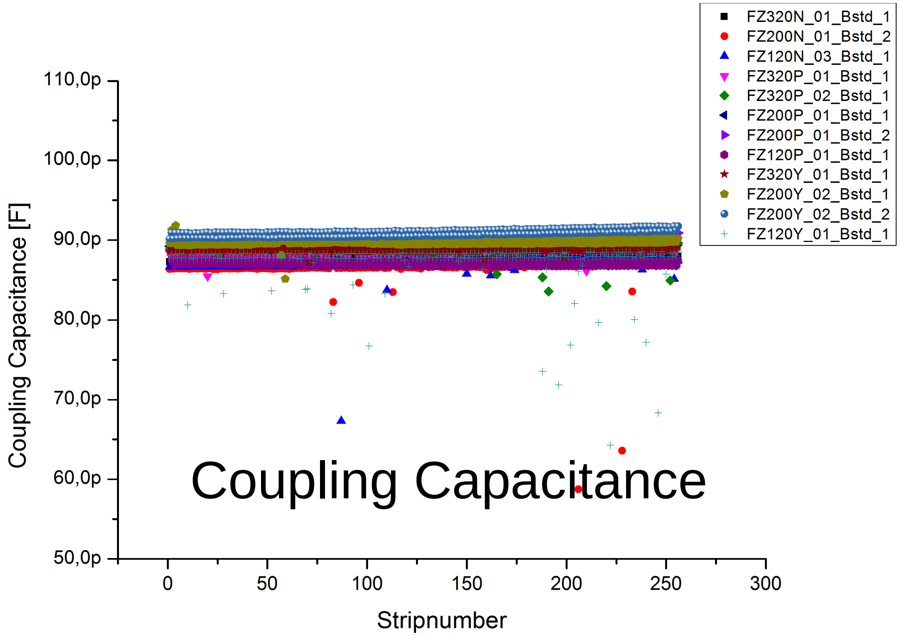
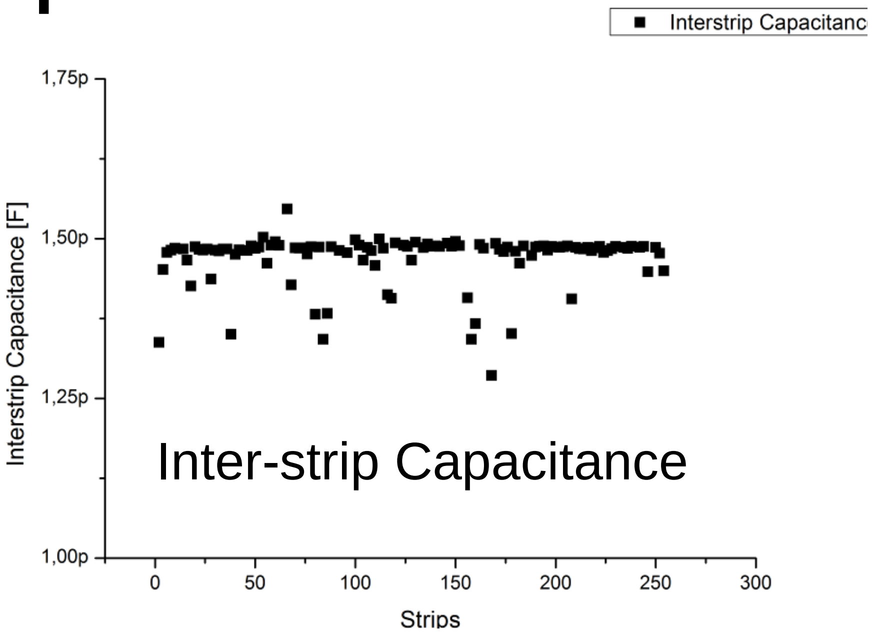


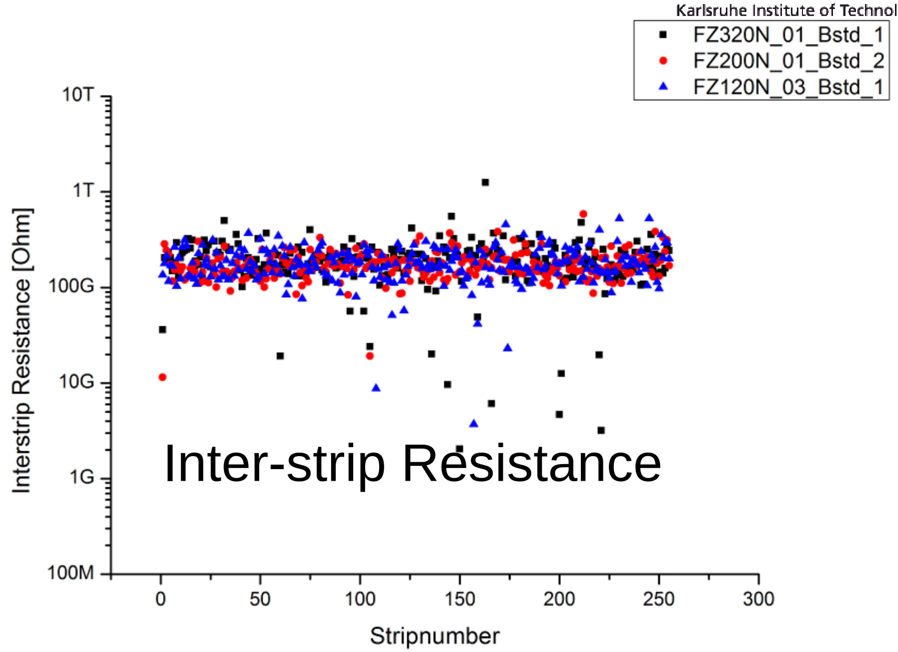


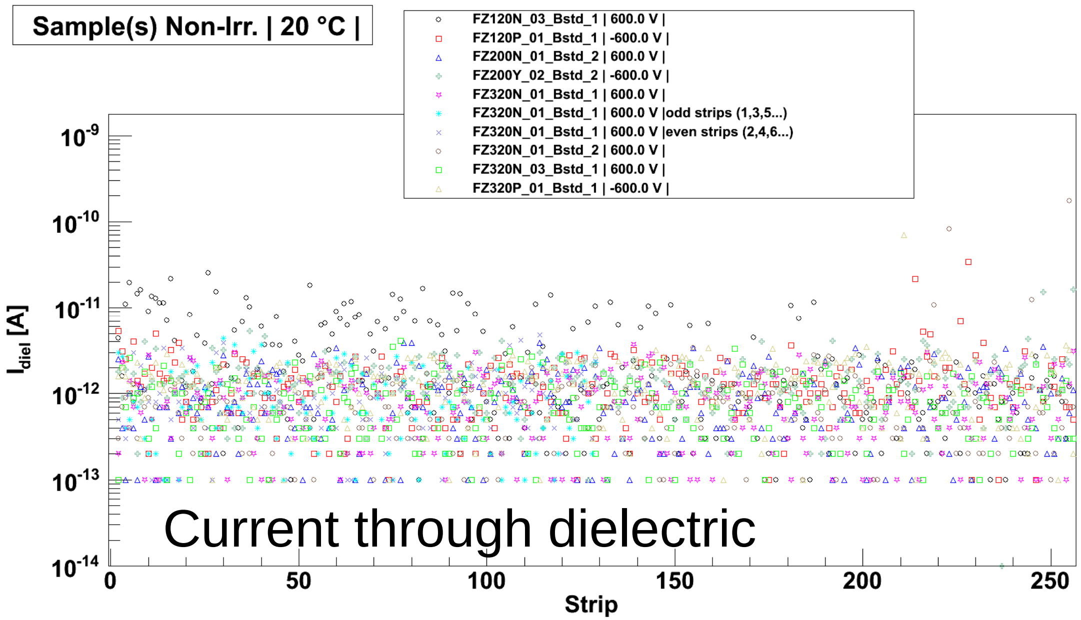


- Higher I_{leak} for strips on thin p-type
- Homogenous strip parameters

Strip measurements







- C_{int} is 0.46pF/cm (p/w~0.225)
  - Agrees well with old CMS production (0.5pF/cm at p/w~0.233)
- 120µm material shows slightly higher current through dielectric

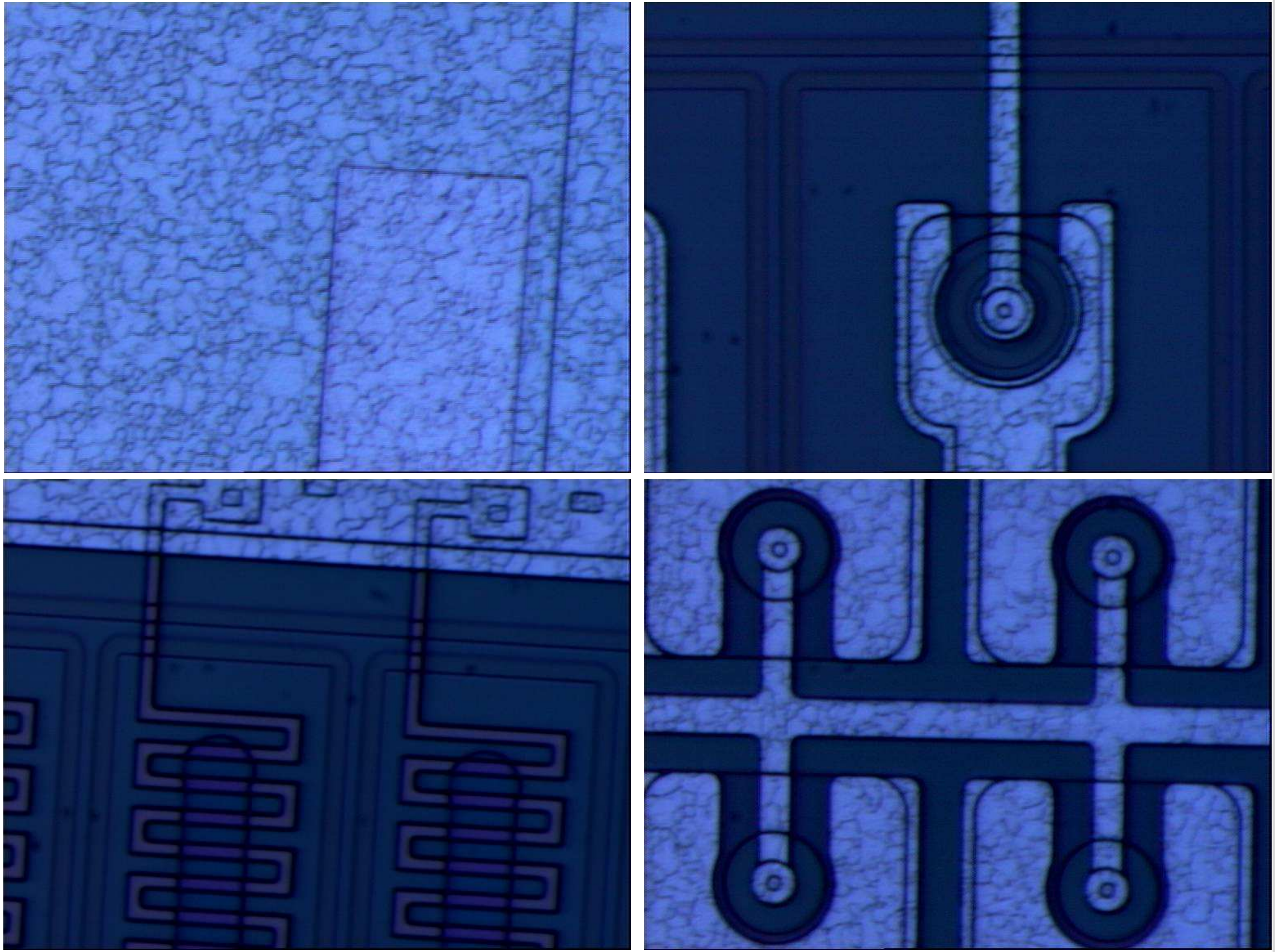
A. Dierlamm
Institut für Experimentelle Kernphysik

Questions on process details

A. Dierlamm
Institut für Experimentelle Kernphysik

Metallization

- On few samples this strange surface structure was found
- Can you explain where this look comes from?



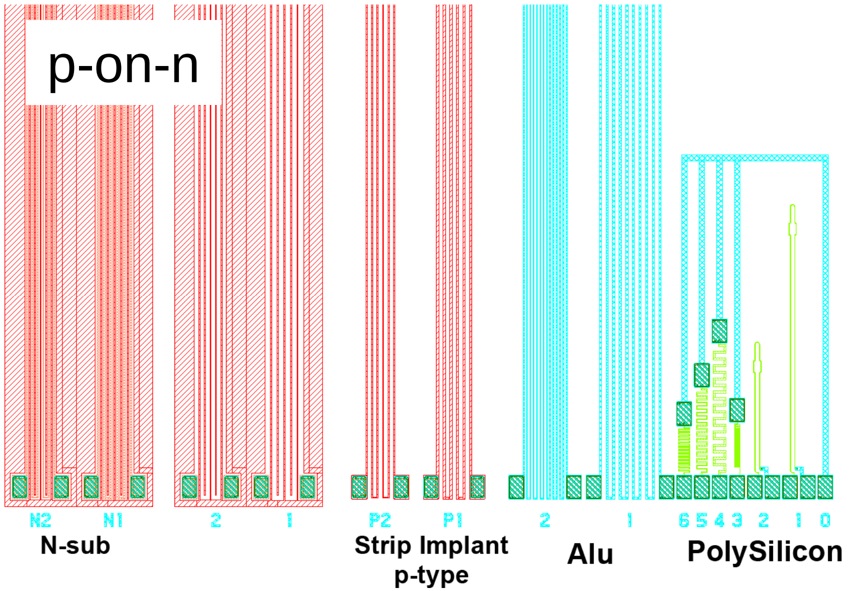
A. Dierlamm
Institut für Experimentelle Kernphysik

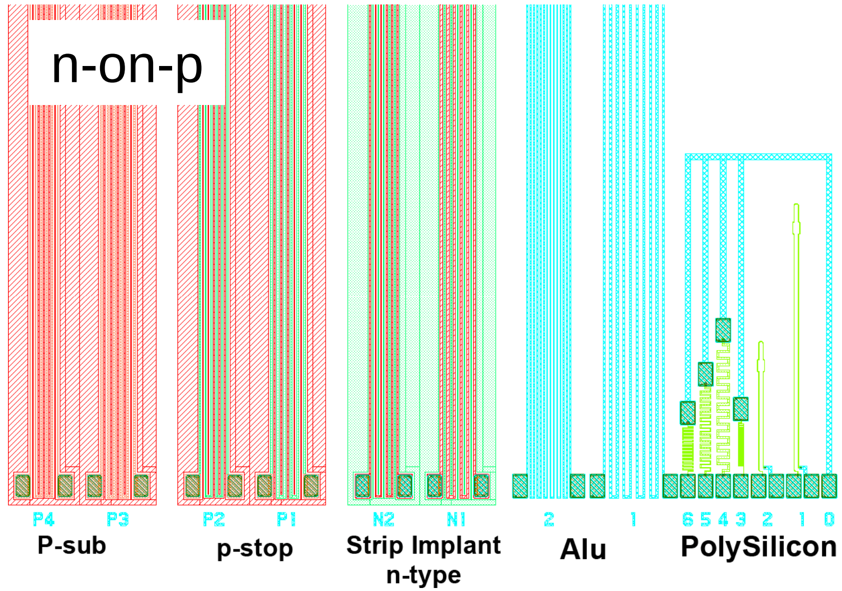
Sheet structure

- The measurement of the strip implants (P1/P2 for N and N1/N2 for Y and P) is known and was already done for the CMS Tracker (p-on-n only).
- For the new strips, which are implants of the same type as the silicon bulk, the measurement is not as easy. They represent n-sub (for n-materials), p-sub and p-stop (for p-materials), where we have no p-n junction but basically an ohmic connection to the silicon bulk.
- Measurement results for these sheet resistor are not as expected (see table). We would expect a factor of 2 between P1 to P2 and P3 to P4 (same material but a factor of 2 in squares).
- There is no difference for the p-stop in P and Y materials, although Y should not have a p-stop implant?
- Measurements done with no bias applied. Would expect that bias is needed. How should we bias?

Test-Struktur	P4 (5870 sq) [kOhm]	P3 (2944 sq) [kOhm]	P2 (5870 sq) [kOhm]	P1 (2944 sq) [kOhm]
FZ320P_01_TS_1	80,5	65,0	129,6	118,0
FZ320Y_01_TS_1	70,7	58,2	118,7	116,5
FZ320P_07_TS_2	82,8	66,5	135,2	118,1
FZ200P_01_TS_1	74,7	61,0	110,2	102,8
FZ200Y_02_TS_1	65,7	54,4	106,7	103,2
FZ120P_08_TS_2	89,3	71,8	143,4	132,7
FZ120Y_08_TS_1	69,7	57,3	113,5	110,7
FZ120Y_05_TS_2	80,8	64,9	139,2	136,5

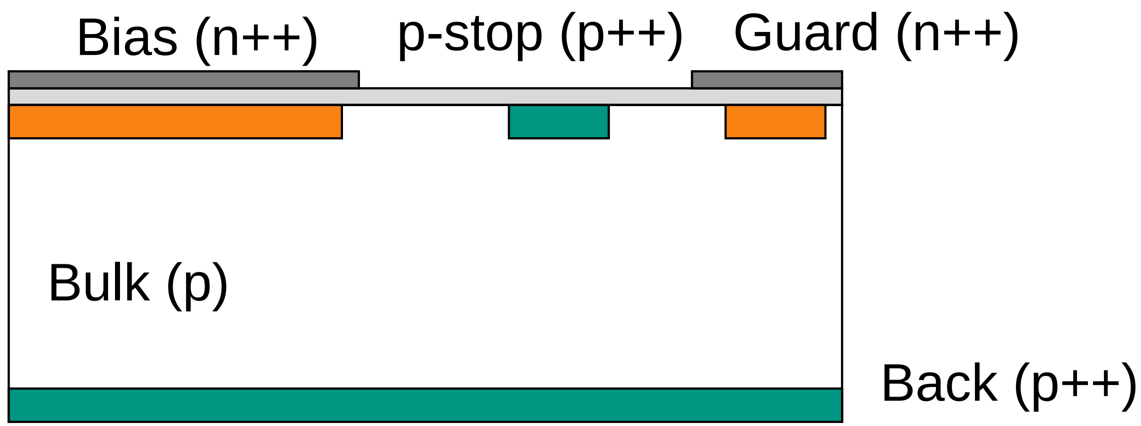
from M. Dragicevic, Vienna





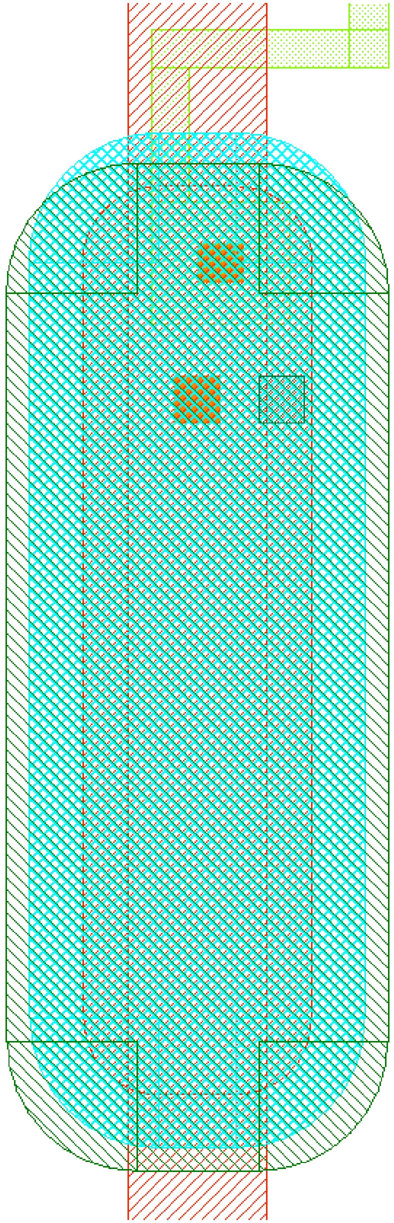
P-stop

- You confirmed that there is no p-stop between bias and guard on p-type diodes and sensors
- This increases HV robustness
  - Why does it work?
  - Where would the break-down occur, if the p-stop is present?
  - ATLAS sensors from HPK have p-stop



Double metal design

- There are places where the upper metal (metal 2) does not cover metal 1, which we considered “bad” design
- Please, share your expertise with us on this issue



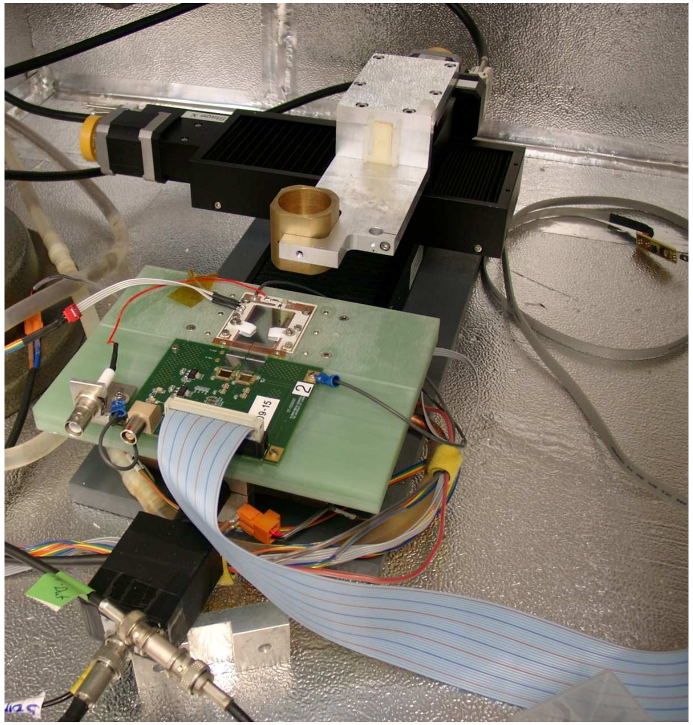
Presentation of this issue was not fully discussed…

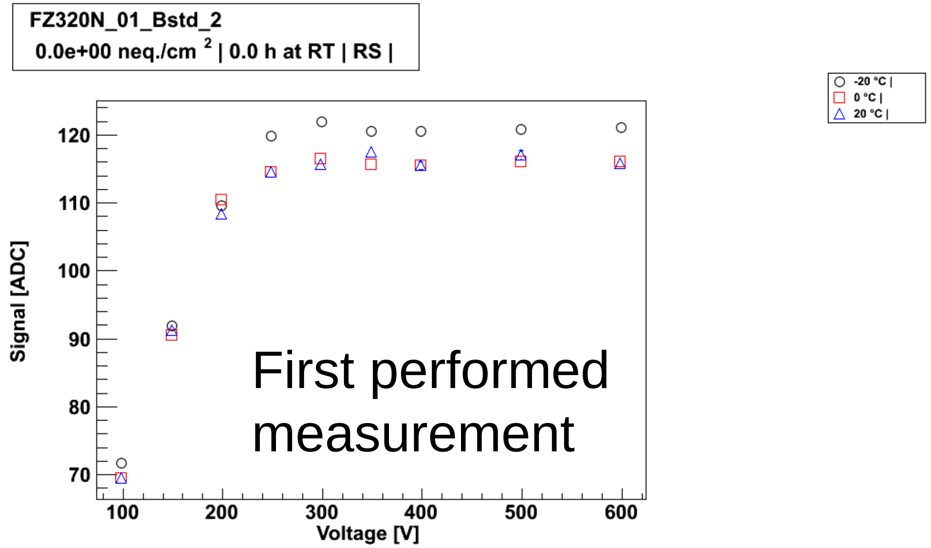
A. Dierlamm
Institut für Experimentelle Kernphysik

Short introduction to further techniques we use

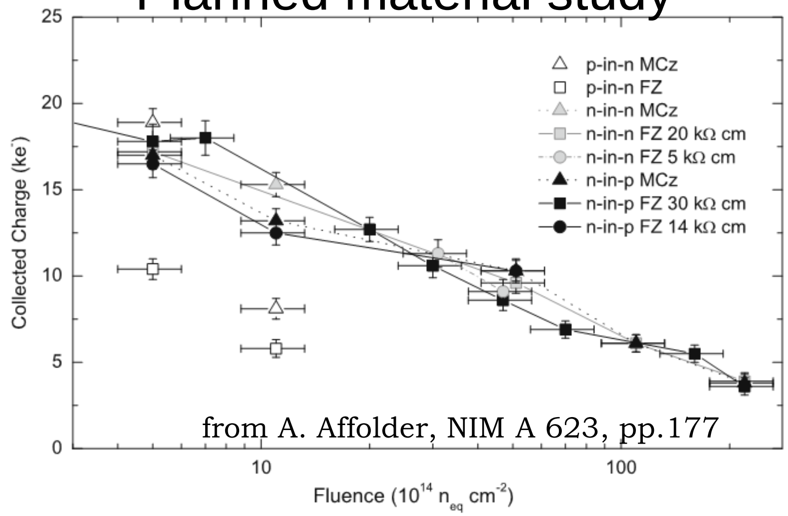
Charge Collection Measurement

- Strip sensors bonded to read-out chip with short shaping time like at LHC
- Charge generation by electron source and laser
- Measurement of collected charge vs. T and U

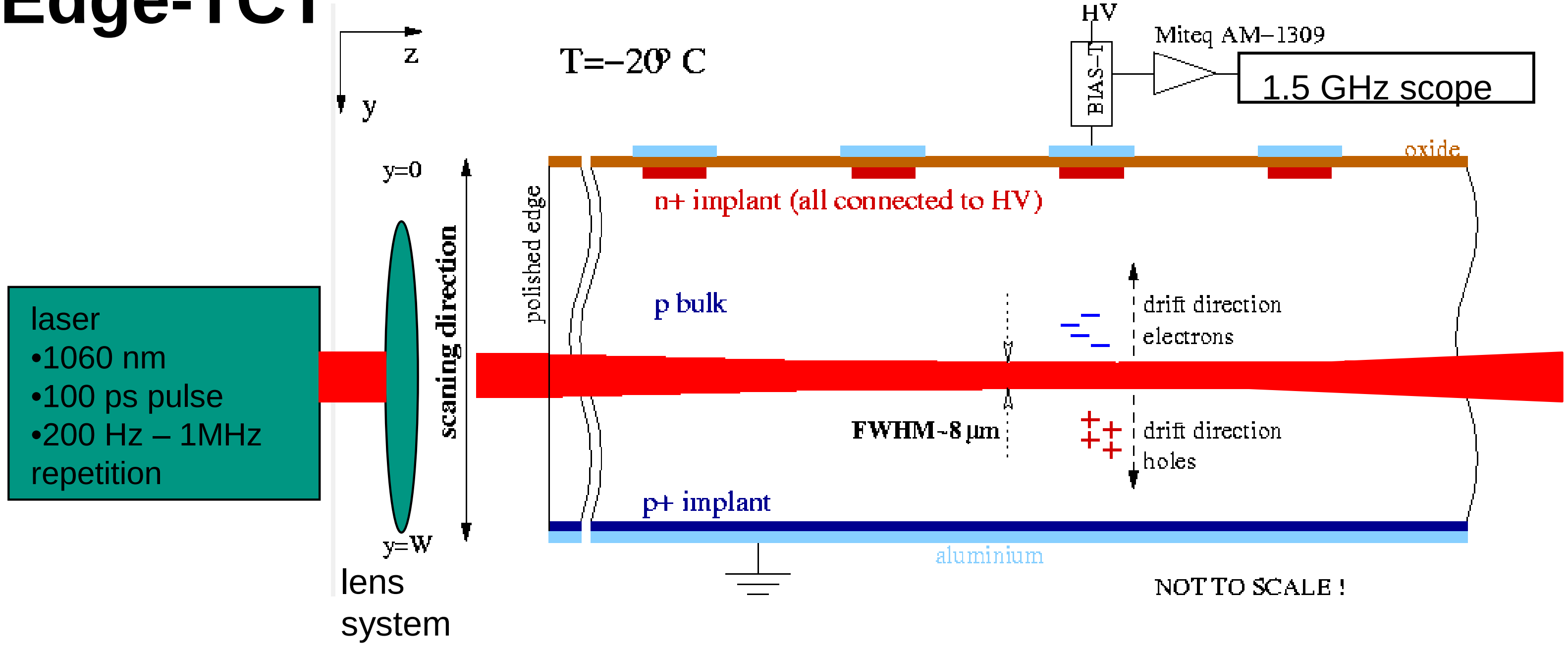




Planned material study



Edge-TCT



detectors on Peltier cooled support in dry air atmosphere (down to -20°C)

<u>Advantages (compared to pixel test beam – grazing technique):</u>

- Position of e-h generation can be controlled by 3 sub-micron moving tables (x,y,z)
- The amount of injected e-h pairs can be controlled by tuning the laser power
- Easier mounting and handling
- Not only charge but also induced current is measured – **a lot more information**

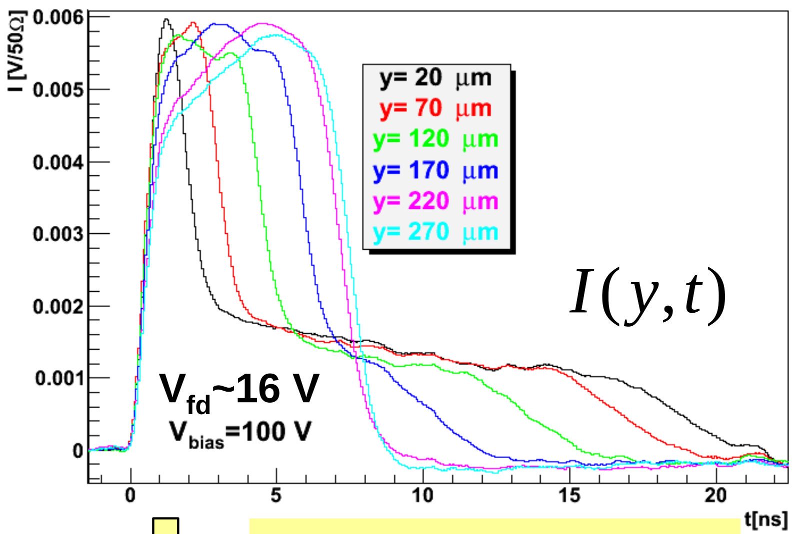
<u>Drawbacks:</u>

- Light injection side has to be polished to sub-micron level to have a good focus – depth resolution
- It is not possible to study charge sharing due to illumination of all strips
- Absolute charge measurements are very difficult

from G. Kramberger, Ljubljana

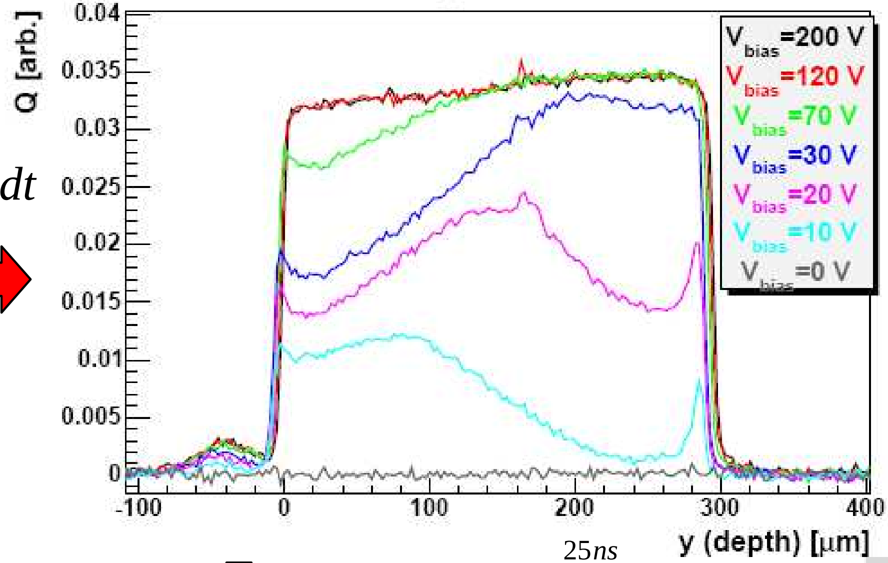
Charge Collection and Velocity Profile

RD50 Micron p-type sensor



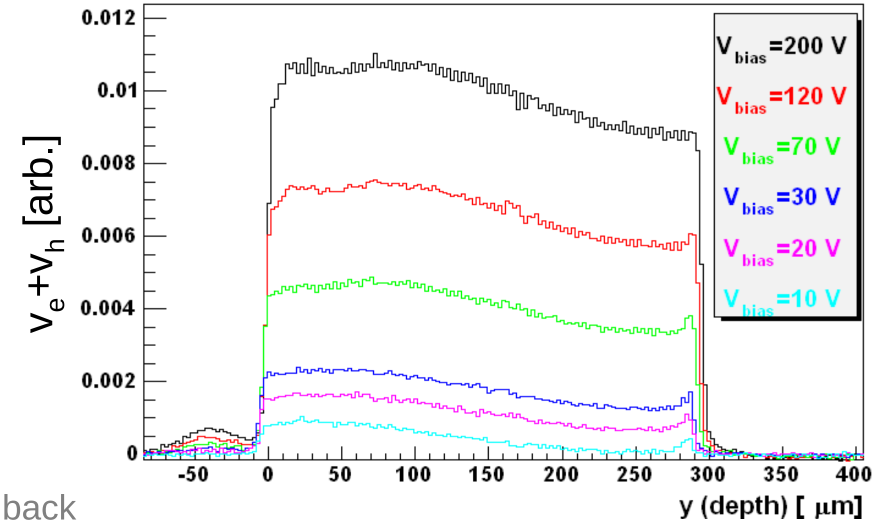
$$Q(y) = \int_0^{25ns} I(y,t)\,dt$$

CHARGE COLLECTION PROFILE

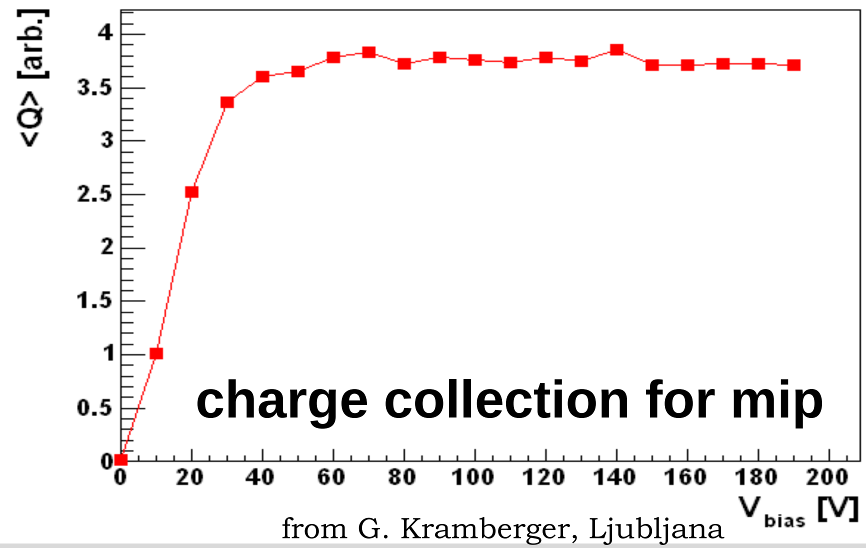


$$I(y, t\sim 0) \propto v_e + v_h$$

VELOCITY PROFILE



$$Q_{mip} \propto \langle Q \rangle = \int_0^{25ns} I(y,t)\,dt$$



from G. Kramberger, Ljubljana

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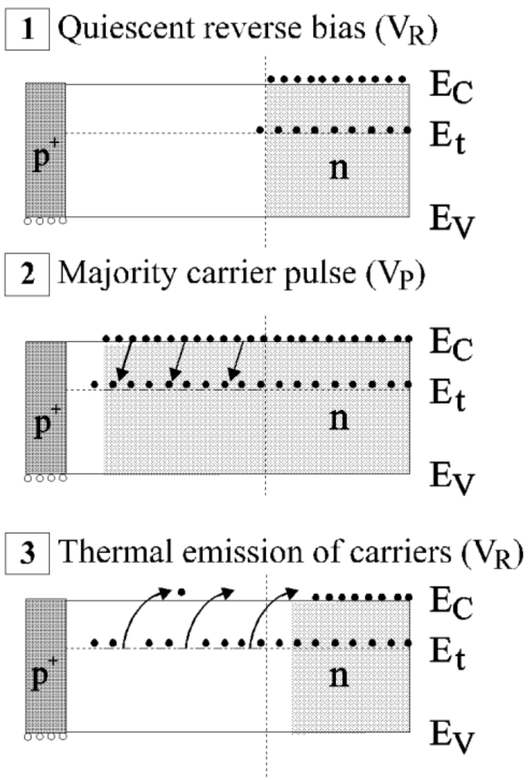
Method

from A. Junkes, UHH

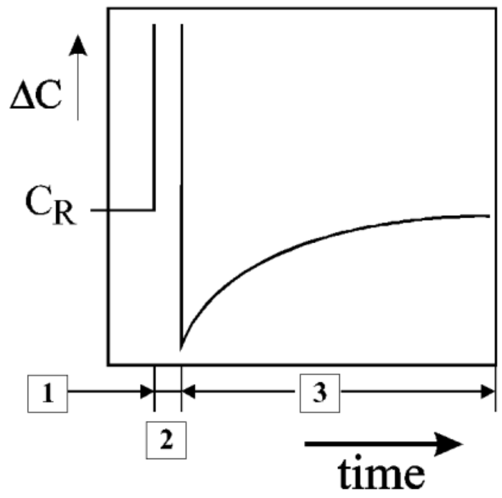


1. Depletion of bulk with V_R
-> defects not filled with electrons

2. Bulk undepleted for short time (100 ms)
-> defects filled with electrons

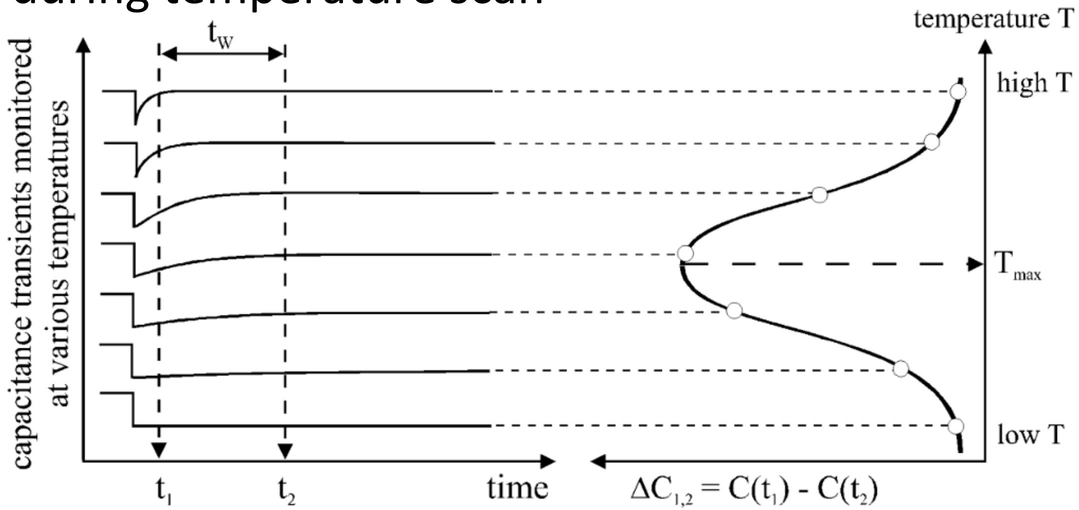
3. Reestablish depletion by applying V_R
-> defects emitt electrons

Capacitance transient



Example:
electron traps
taken from PhD
thesis M. Moll 1999.

Measurement of capacitance as function of time during temperature scan



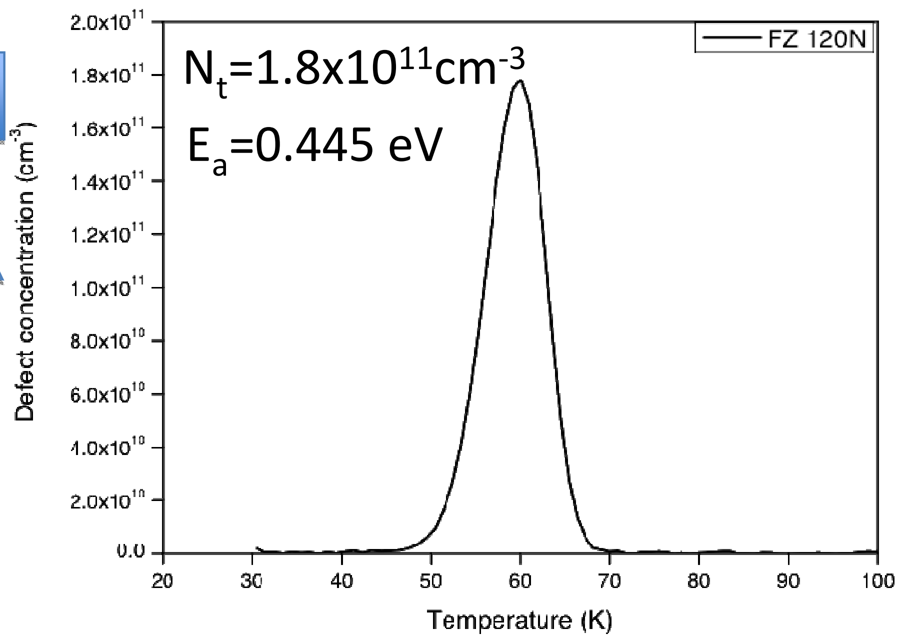
Simple ansatz: $\Delta C = C(t_1) - C(t_2)$
More complex: $\Delta C = \Delta C_0 \exp(-e_n t)$

Evaluation

from A. Junkes, UHH

Defect concentration via $N_t \approx 2N_D|\Delta C|/C_R$

N_D= Original doping
ΔC= DLTS capacitance signal
C_R= Reverse capacitance



Temperature equivalent to energy in band gap -> peak maximum: localisation of level in E_G

In our Lab more complex ansatz:
- 3 time windows for data taking
- convolution with 18 T-dependant functions eg. sin, cos...

–> Allows Arrhenius evaluation

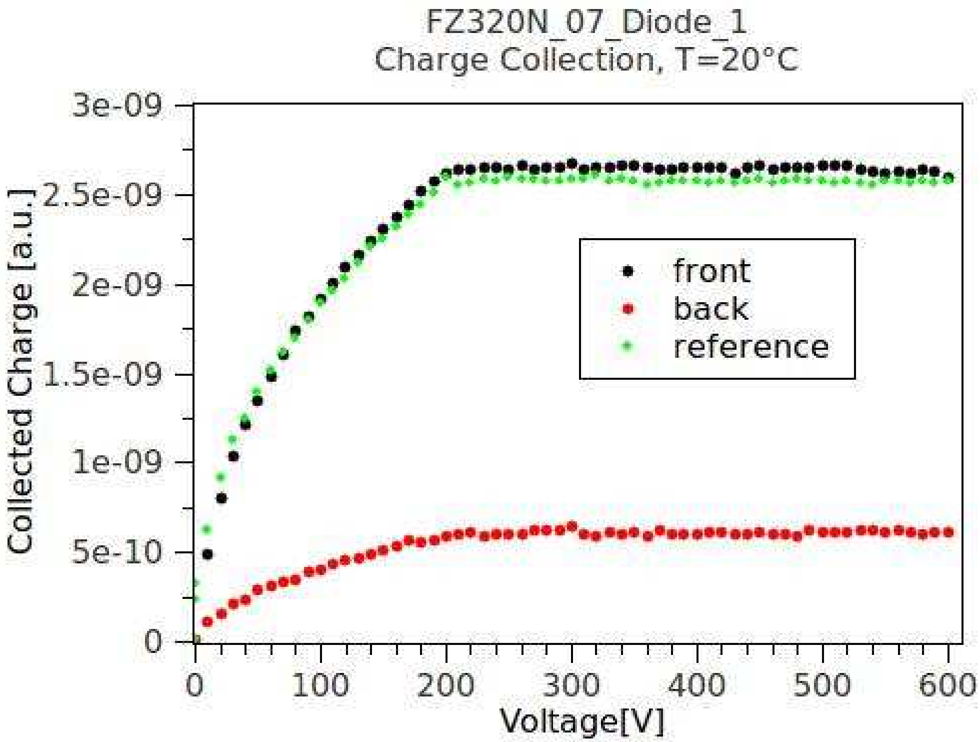
Multi shot method –> each measurement point shows full defect concentration depending on emission rate
–> peak max = full defect concentration
Peak fitting –> additional information about cross sections and activation energy

Additional measurements:
- Depth profile of defects
- Direct measurement of cross sections and activation energy
- Majority and minority carrier filling possible with light & electrically

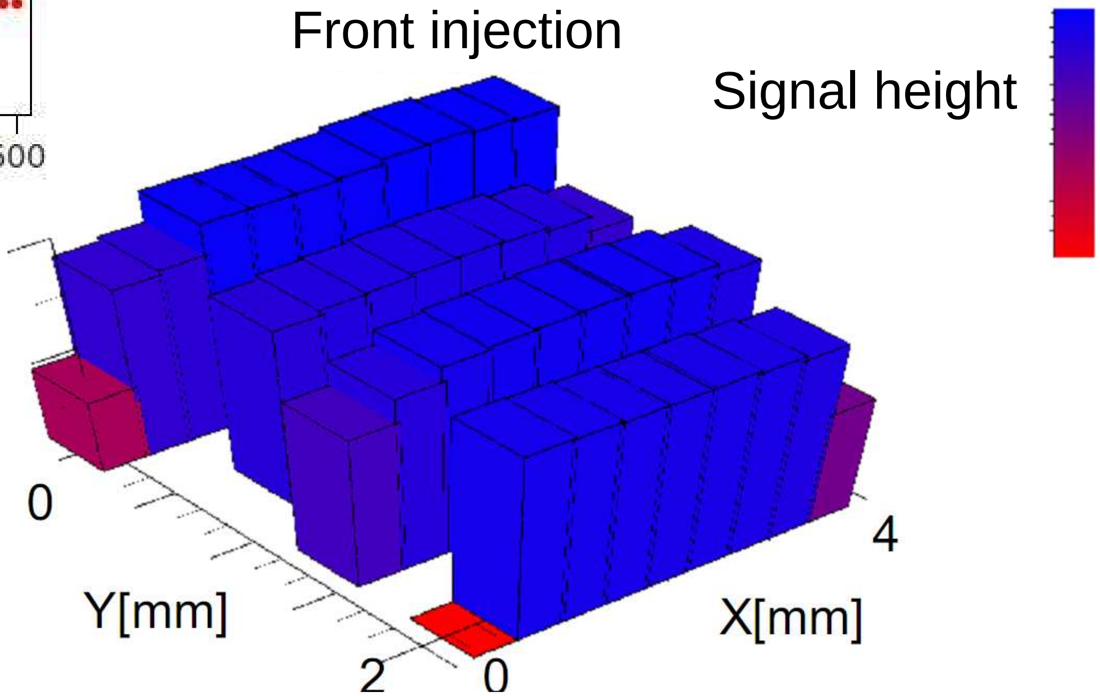
back

Backup

CCE on Diodes



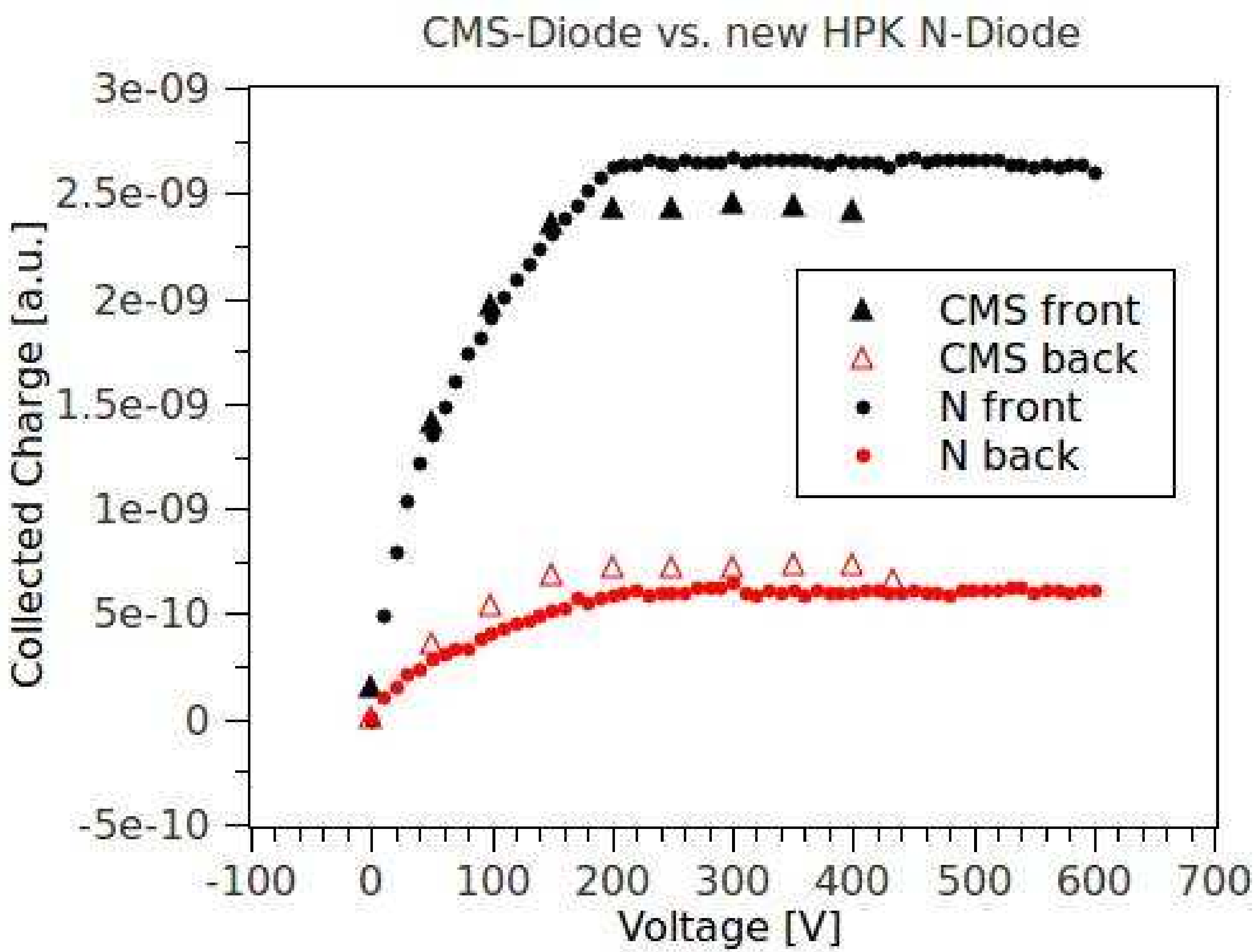
Reference is same as "front" measured after several other measurements.
=> Signal variations within 3%



No reflections on back-side grid visible in signal height

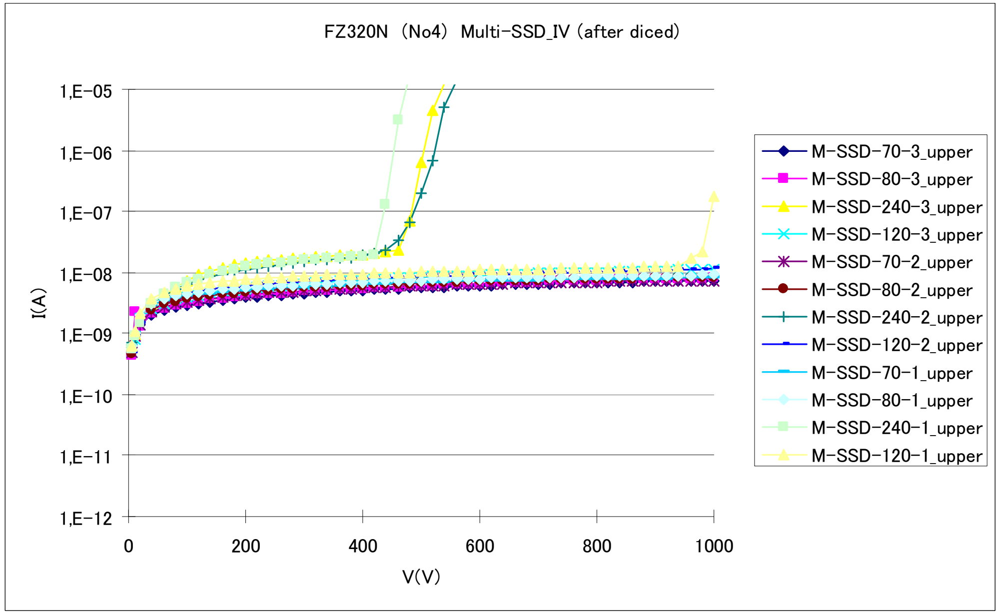
Collected charge with 1060nm laser

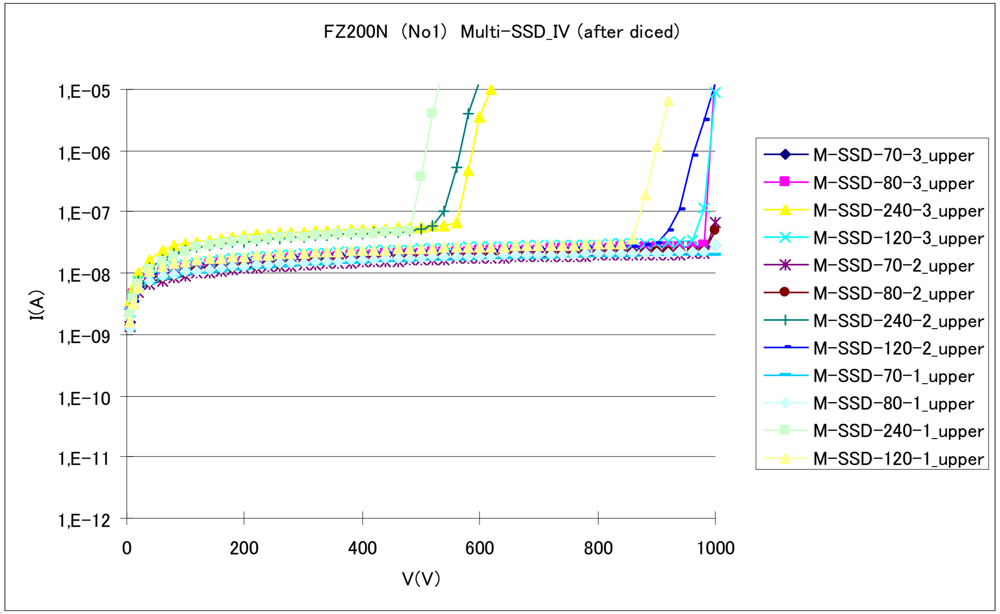
- Similar behavior on old production with etched opening on back

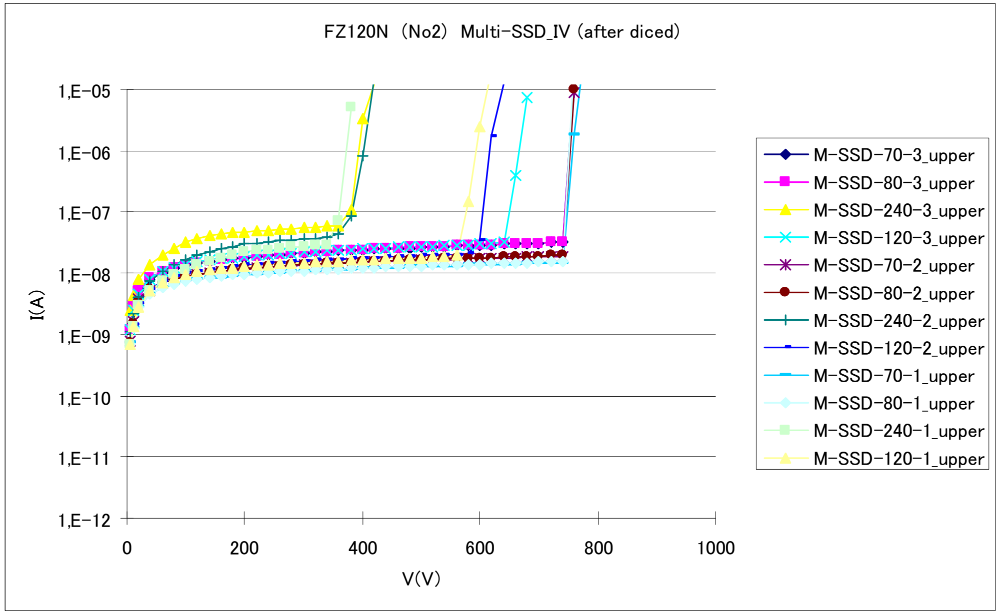


Low break-down voltage on Multi-SSD 240µm pitch

- **N-type**
- 120N has lower break-down on 120µm pitch as well

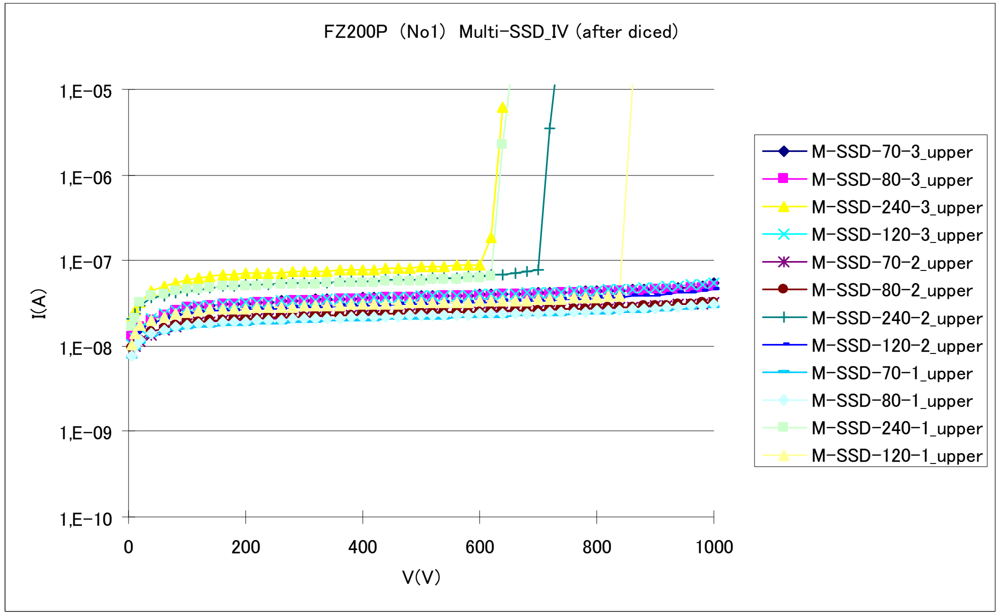


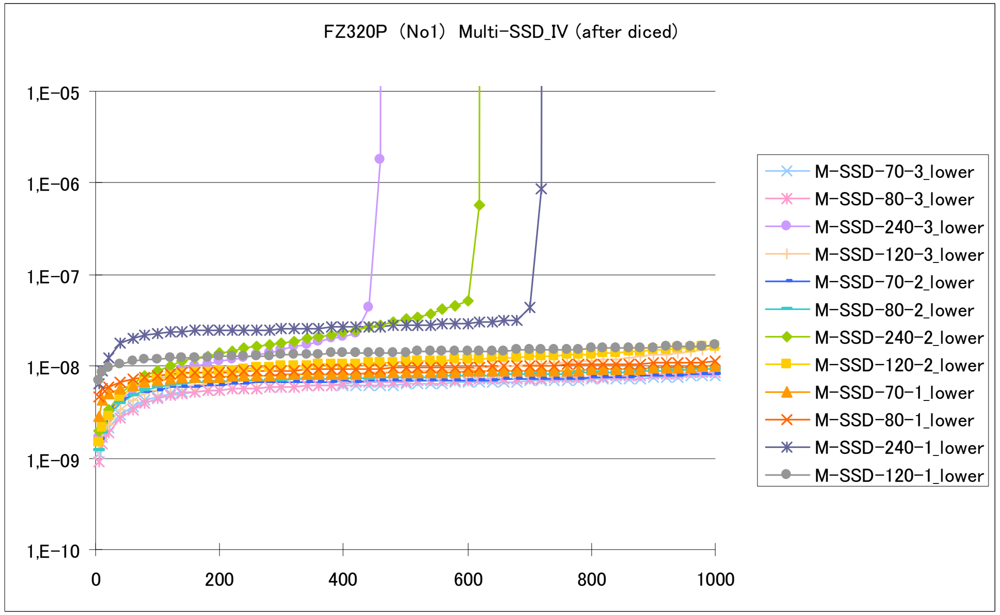




Low break-down voltage on Multi-SSD 240µm pitch

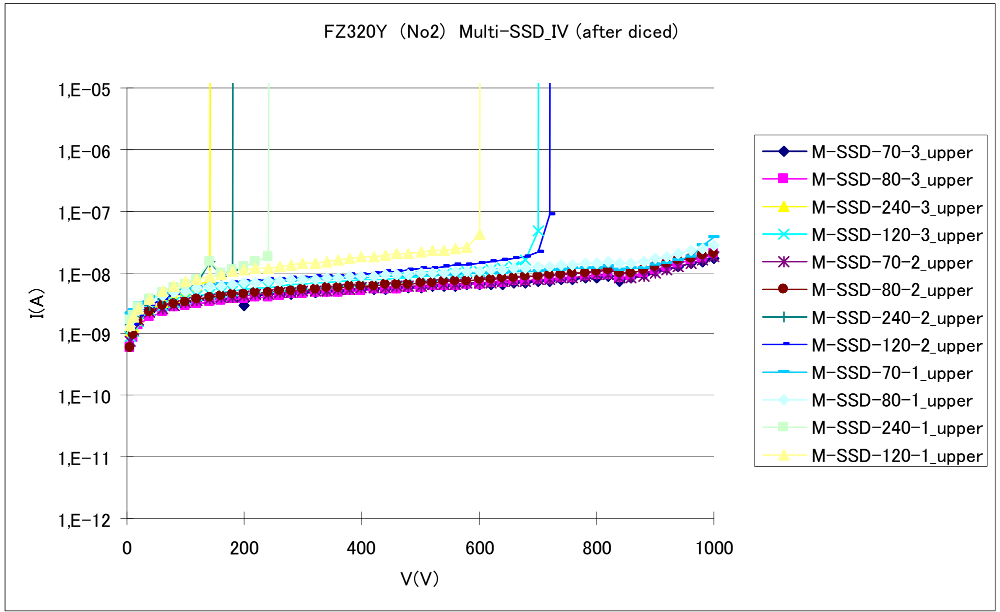
- **P-type**

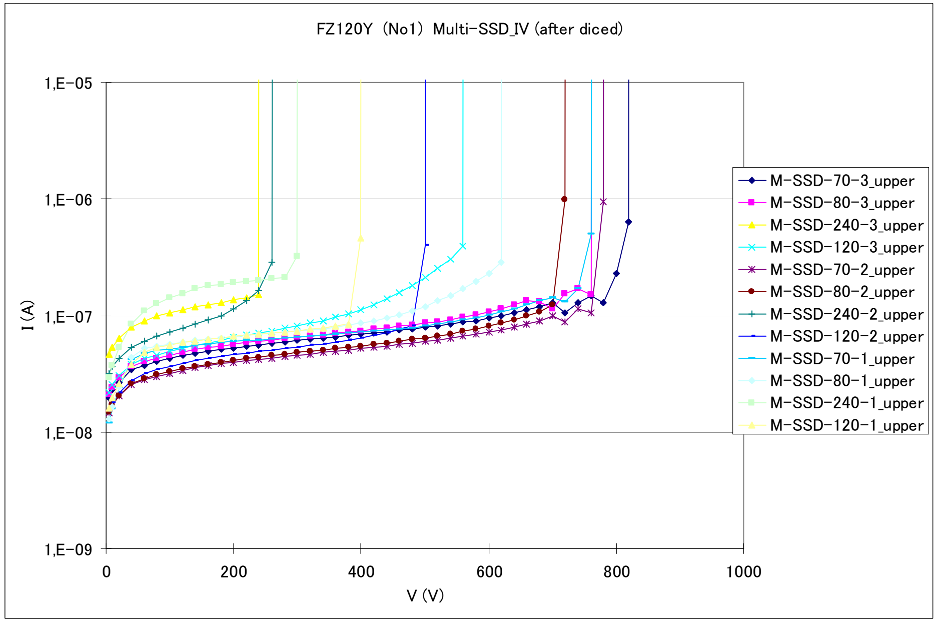




Low break-down voltage on Multi-SSD 240µm pitch

- **Y-type**
- Bad on 120 pitch structures as well



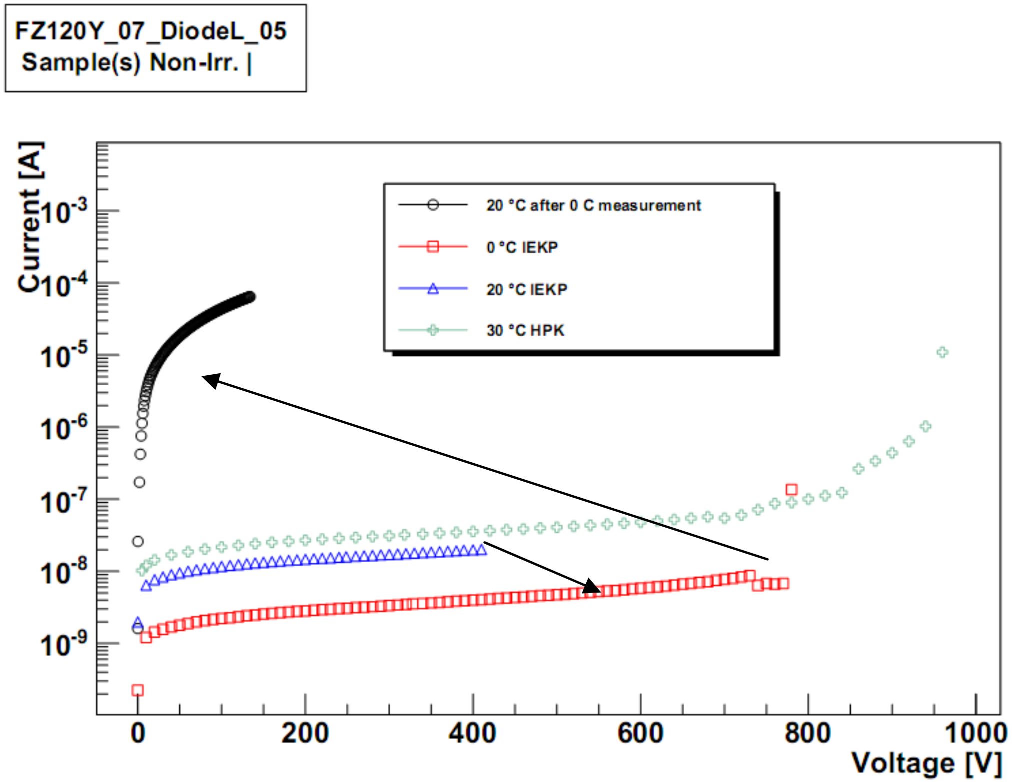


Additional new diode for high precision measurements

- For future projects we might want an **additional** diode for use in high precision measurements of volume generated current and capacitance
- For this we need to contact a guard ring to generate a known field configuration
- With use of such a guard ring we might need additional surrounding floating guard rings
- Do you have such a diode in your library?
- How would you suggest the p-type diode should look like?
- Adding a p-stop here would be necessary to isolate the guard ring from the bias implant. This might decrease HV robustness, but could be acceptable for **this special diode**.

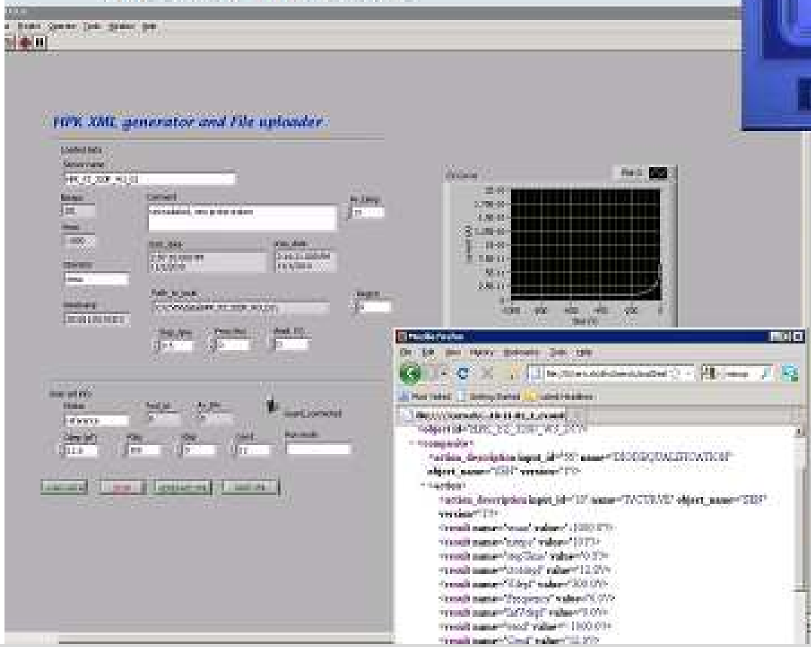
Jump in leakage current after break-down and cooling ?

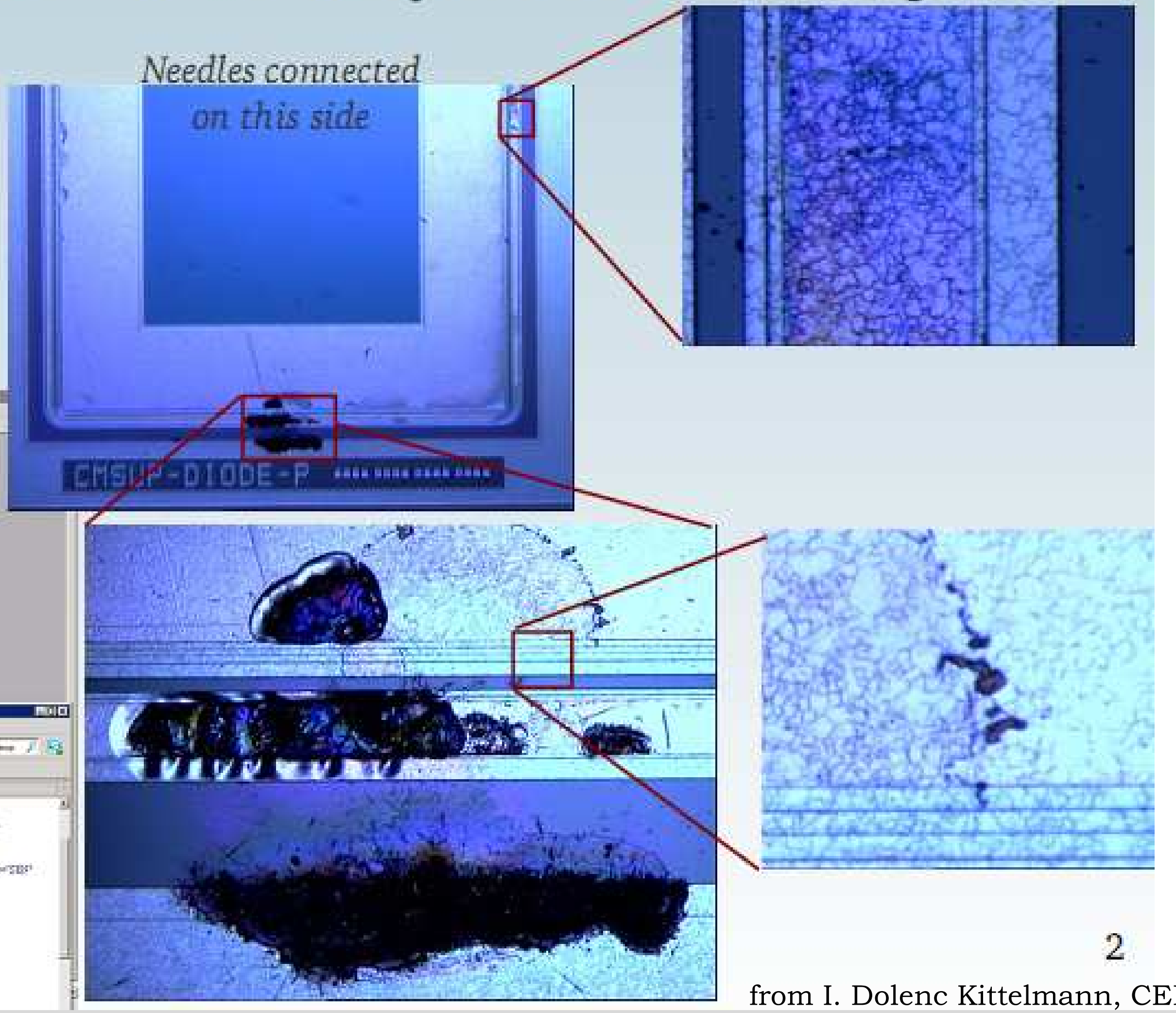
- Current jump appeared between 0℃ and -20℃ measure ment
  - FZ120Y_07_DiodeL_5
  - FZ200Y_06_Diode_1
- Current jump appeared between 20℃ and 0℃ measurem ent
  - FZ120Y_08_DiodeL_5
  - FZ200Y_08_DiodeL_5



Diodes: CV/IV

- Measured diodes with new CV/IV setup
  - FZ_120Y_W5_D1, FZ_200Y_W8_D1, FZ_320N_W8_D2: guard connected
  - FZ_320P_W3_D1: guard not connected (reached compliance of 1mA at ~10V if guard ring connected...)
  - FZ_200Y_W8_D2 broke down during the measurement...
- Chiller broke... send to repair, will have it back next week
- Software for generating XML files for DB done





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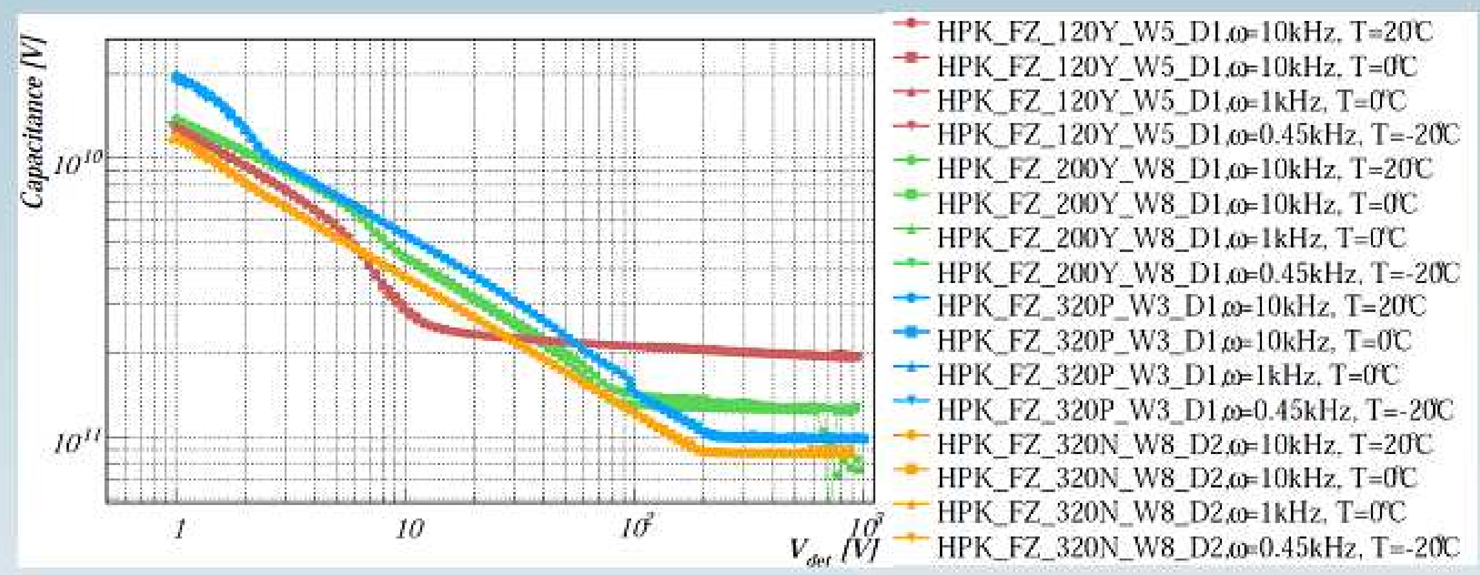
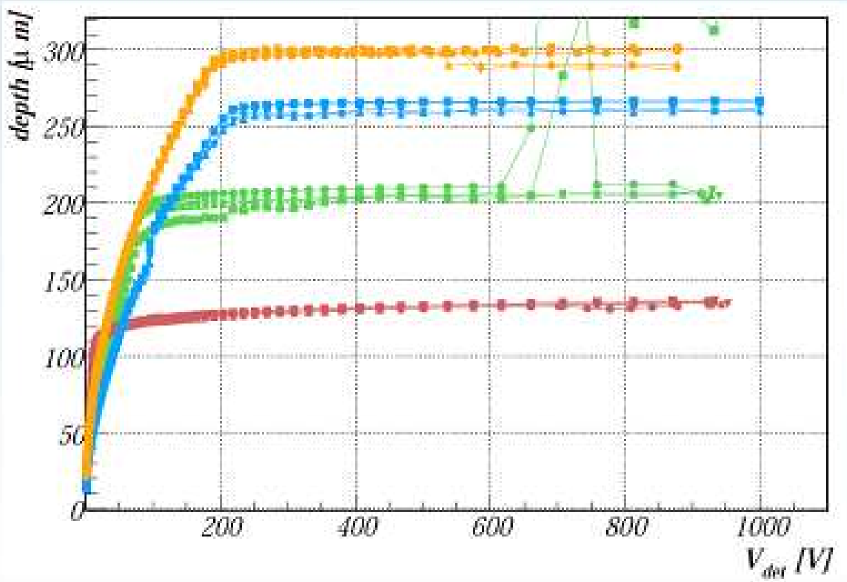
from I. Dolenc Kittelmann, CERN

Diodes: CV





- Observations
  - FZ_120Y_W5_D1: C not saturated even at 1000V, similar with FZ_200Y_W8_D1
  - Extracted thickness agrees up to ~20μm, apart for FZ_ 320P_W3_D1
    - FZ_120Y_W5_D1 135μm @1000V
    - FZ_200Y_W8_D1: 205-212μm @ 1000V
    - FZ_ 320P_W3_D1: 260-265μm
    - FZ_320N_W8_D2: ~300μm

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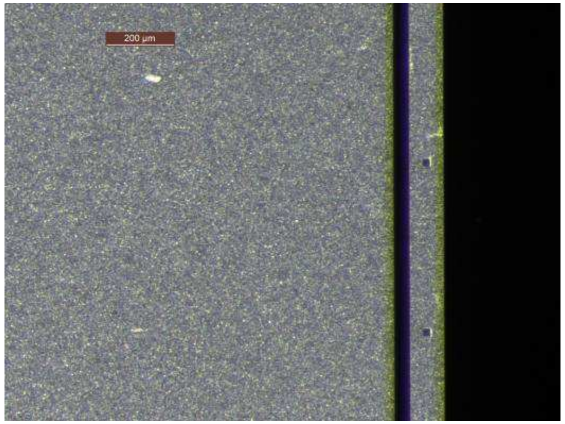
from I. Dolenc Kittelmann, CERN

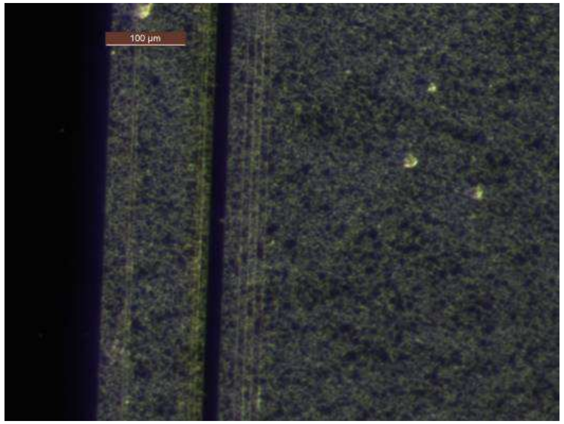
Metallization

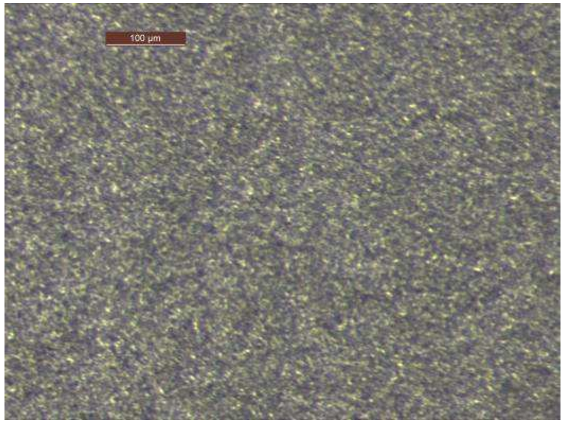
Old production

New production



Front





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