Studies on n and p-type MCz and FZ structures of the SMART Collaboration irradiated at fluences from 1.0 E+14 to 5.6E+15 p cm^{-2}

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SMART Collaboration

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Overview

- The SMART run I and II: layout and material
- Pre-irradiation measurements
- Irradiation fluences and layout
- Experimental set-up
- Results on diodes and mini.sensor for n and p-type MCz and Fz at ϕ = 1.0 and 4.4 E+14 p cm^{-2}
- Results at ϕ=5.5 E+15 p cm^{-2}

Wafer layout - SMART

Pad detector

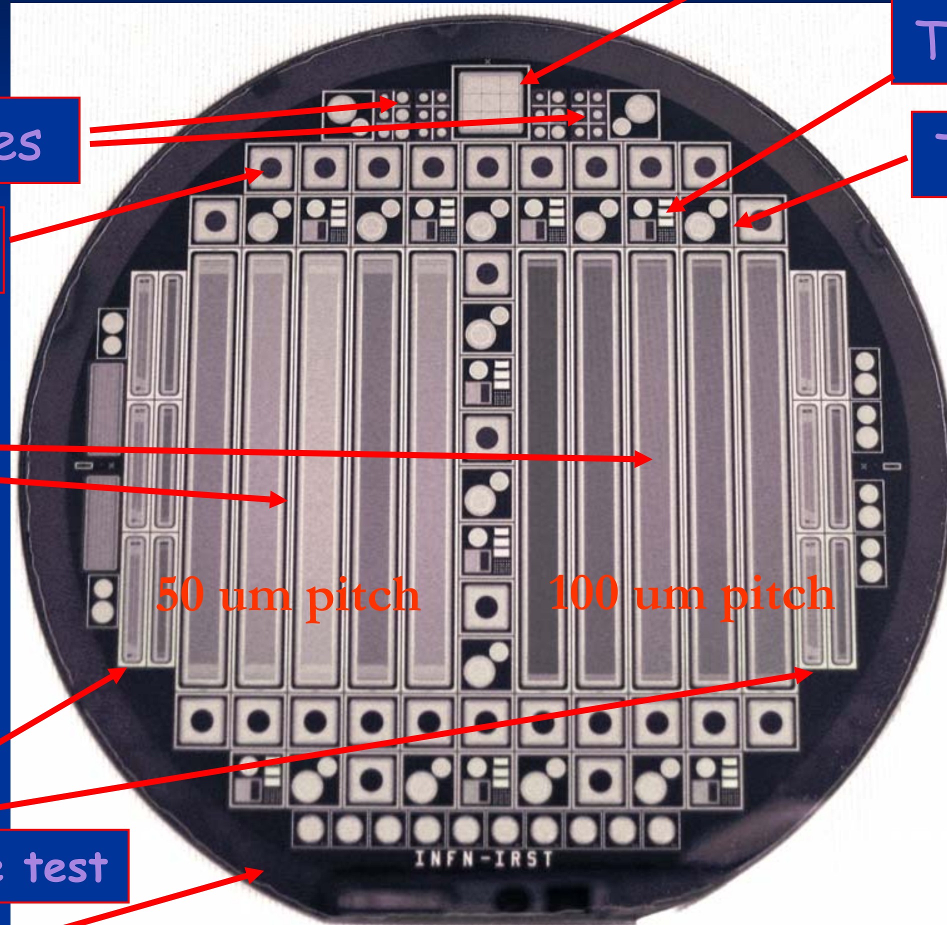
Test2

Test1

Edge structures

Square MG-diodes

Microstrip detectors



Inter strip Capacitance test

Round MG-diodes

RUN I p-on-n

22 wafers
Fz, MCz, Cz, Epi

RUN II n-on-p

24 wafers Fz, MCz

Material under investigation

- p-on-n MCz <100> ρ> 500 Ω cm

standard process — W364
no LTO, sintering @ 380 °C — W115,W130,W164
no LTO, sintering @ 380 °C + TD killing — W160

- n-on-p MCz, no OG <100> ρ> 1.8 KΩ cm

low dose p-spray 3E+12 cm^{-2} — W66
high-dose p-spray 5E+12 cm^{-2} — W182

- Fz reference samples

n-type <111> — W1254 (std) , W1255 (T=380 C)
p-type (passivated) — W14 (low dose p-spray), W37 (high dose p-spray)

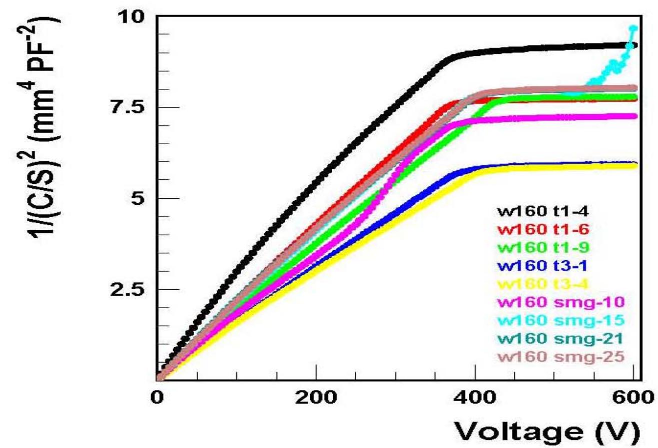
Pre-irradiation measurements

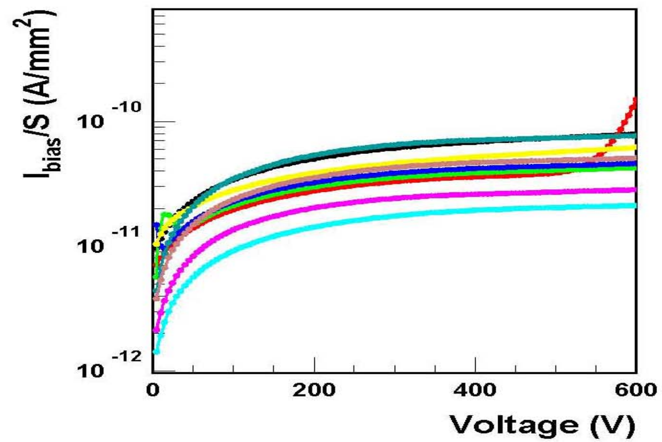
- Bulk current & Depletion Voltage
  - Diodes & Mini-sensors
- Strip capacitive load
  - Cap-ts & Mini-sensors
- Surface current
  - GCD (Metal, Poly)
- Oxide trapped charge
  - MOS

Wafers qualified : Fz, MCz (n) , MCz(p) , Cz

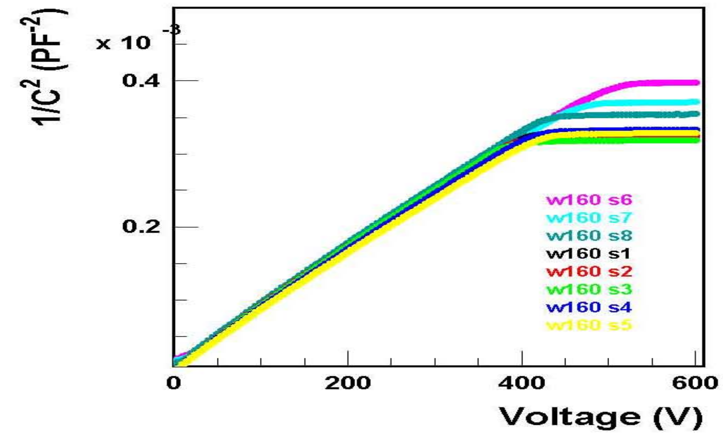
Wafer MCz *n-type* 160 pre irr

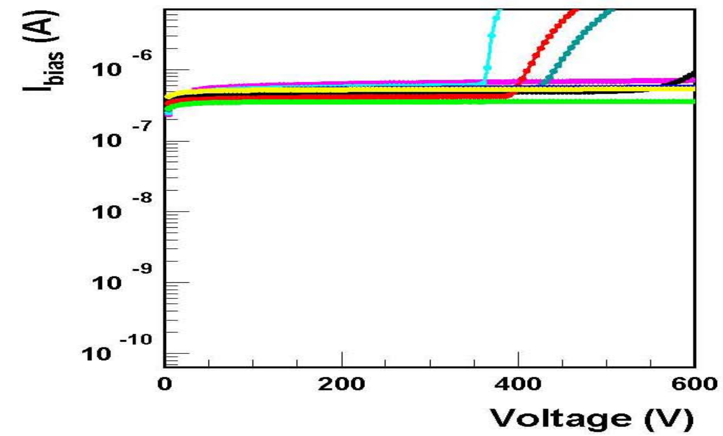
Diodes





Mini-sensors

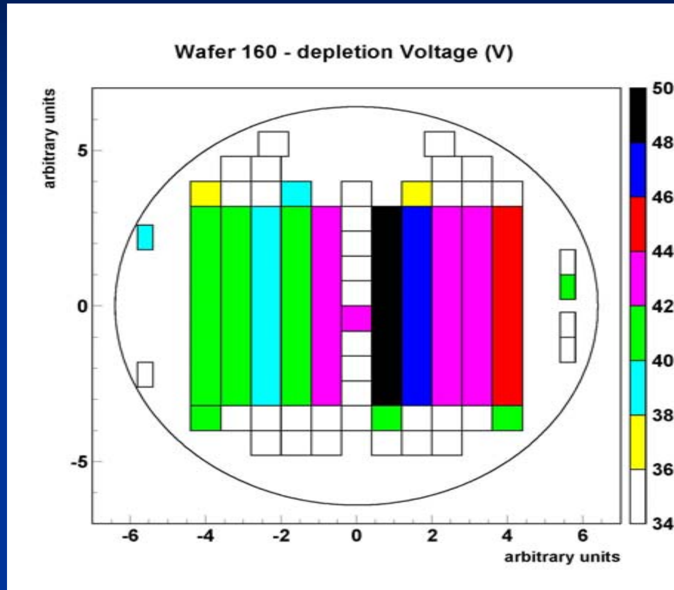




Mapping of the wafer resistivity

Wafer MCz n-type 160

380 < Vdepl mini-sensor < 500 V



Wafer MCz p-type

Measured in IRST

Strong variation of the bulk resistivity both in n-type and p-type MCz wafers.

This reflects also in the depletion voltage spread for the mini-sensors.

MCz n-type – no LTO -

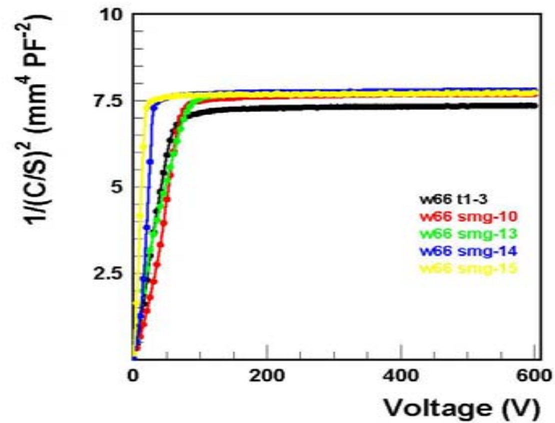
W164 430 < Vdepl < 520 V

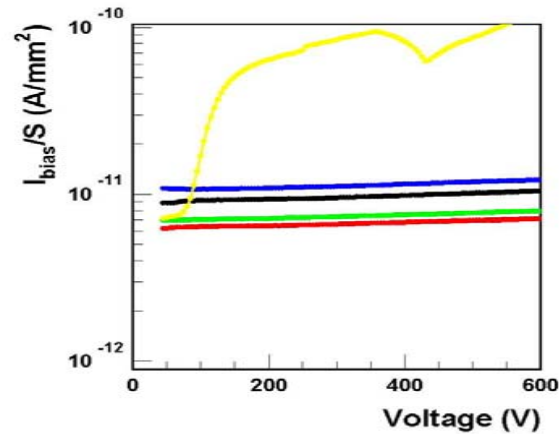
W115 520 < Vdepl < 580 V

W130 400 < Vdepl < 460 V

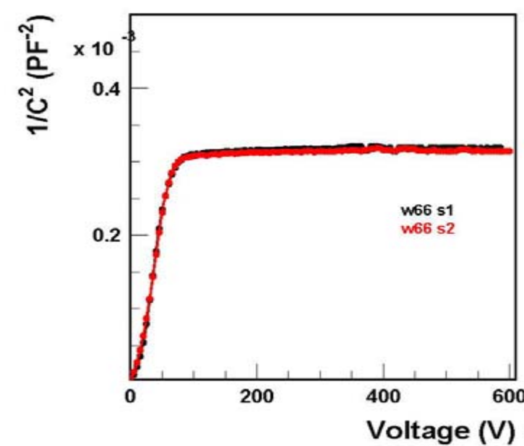
Wafer MCz *p-type* 66 pre-irr

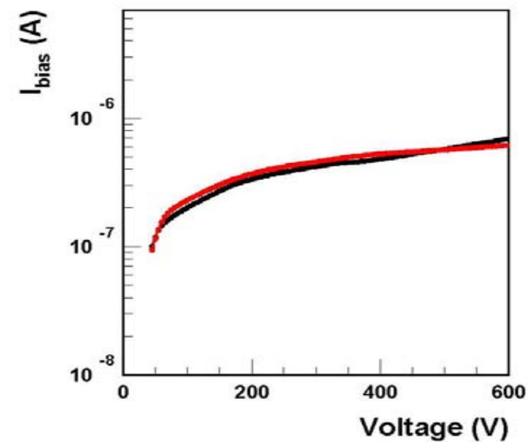
Diodes





Mini-sensors





MCz and Fz p-type mini-sensors of 100 μm pitch show an early breakdown before irradiation.

The problem may be related to the fact that no special mask has been used to diffuse the p-spray.

Irradiation Fluences- SPS 24 GeV protons

	$p\ cm^{-2}$		$p\ cm^{-2}$		$p\ cm^{-2}$
Total	9.63E+13	Total	4.42E+14	Total	5.56E+15
TR	8.06E+13	TR	4.19E+14	TR	5.35E+15
TL	8.56E+13	TL	4.16E+14	TL	4.92E+15
BR	1.13E+14	BR	4.34E+14	BR	5.95E+15
BL	1.18E+14	BL	4.50E+14	BL	5.48E+15

• A hardness factor of 0.62 for the 24 Gev protons has been adopted when calculating the alpha parameter

Irradiated Structures

		n		*n*	*n*			*n*	*p*		*p*	
		FZ		MCz 380 noLTO	MCz 380 noLTO			MCz	MCz		FZ	
	fluenza (p)			TD killing					low p-spray	high p-spray	low p-spray	high p-spray
TR	5.35E+15	1254 SMG-11		160 SMG-25	130 T1-10	164 T1-9		364 SMG-11		182 SMG1	14 SMG-14	
TL	4.92E+15	1254 SMG-21		160 :T1-4, T1-9	130 T1-5	164 T1-4		364 SMG-21		182 SMG15	14 SMG-1	
BR	5.95E+15			160 :T3-4, T2-6		164 SMG 11		364 T1-10		182 SMG13		
BL	5.48E+15			160 T2-4		164 SMG 25		364 T2-5		182 SMG25		
				S10,S5	*S9*	*S4,S10*		S5		*S4,S2*		
TR	4.19E+14			160 T1-6		164 : T2-6, T1-5	115 SMG-15	364 Tl-5	66 SMG-10	182 SMG-10		37 T1-10
TL	4.16E+14	1255 SMG-11		160 SMG 21	130 T1-5	164 : SMG-21, T1-10	115 : SMG-17, T2-6	364 SMG-10	66 SMG-13	182 SMG-11		
BR	4.34E+14			160 T3-3	130 :T1-6, T2-4				66 SMG-15	182 T1-6	14 SMG-10	37 T2-3
BL	4.50E+14	1255 T1-9	SMG-17	160 T2-4	130 T1-9			364 T2-1		182 T2-1, T2-3	14 : SMG-13, T1-3	
			S3	*S9*	*S7*	*S5,S6*	*S3*	*S1*	*S1*		*S1*	*S1*
TR	8.06E+13	1255 T2-1	1254 SMG-25			164: T2-2	115 T1-4		66 T1-3	182 SMG-9	14 SMG-15	
TL	8.56E+13			160 SMG-10	130 T1-4	164: SMG-17	115 T1-5	364: T3-1, T2-2		182 T1-8		
BR	1.13E+14	1255 T1-6		160 T3-1	130 T2-1		115 T2-1	364 T1-4			14 SMG-2	
BL	1.18E+14	1255 SMG-10		160 T2-1				364 SMG-17	66 SMG-14	182 SMG-12		37 T2-1
		S1	*S9*	*S1*	*S2*	*S3*	*S4*	*S2*	*S2*			*S4*

Irradiation set-up

The diodes and the the test-structures T1, T2 and T3 have been placed orthogonally to the beam direction

The mini-sensors (active area=0.32 x 4.5 cm^2) have been placed with an inclination of about 26° to be irradiated uniformely by the beam (section = 2x2 cm^2)

Experimental Set-up in Firenze and Pisa

Firenze

- Karl-Suss Probe-Station instrumented with a Thermo-Chuck and an air-chiller that can operate in the temperature range
  $-40\ ^{\circ}C < T < 200\ ^{\circ}C$z

Pisa

- Karl-Suss Probe-Station SOM3
  Chiller : - 40 °C +80 °C
  Chuck liquid cooled

Measurement procedure

❖ The structures have been kept in the fridge ($T < -10$ °C) whenever not in use

❖ A first measurement (IV and CV) has been performed before any annealing

❖ Two annealing temperatures have been used for these structures: 60°C and 80°C

❖ After each annealing step the following measurements have been performed:

I-V curves at T=20°C or at 0°C

CV curve at T=0°C and f=10 KHz

❖ Alpha parameter calculated with currents at depletion voltage + 50 V, at T=20°C (or with currents at T=0°C normalized to T=20°C) , after 8 minutes at $T_{annealing}$=80°C or 80 minutes at $T_{annealing}$=60°C

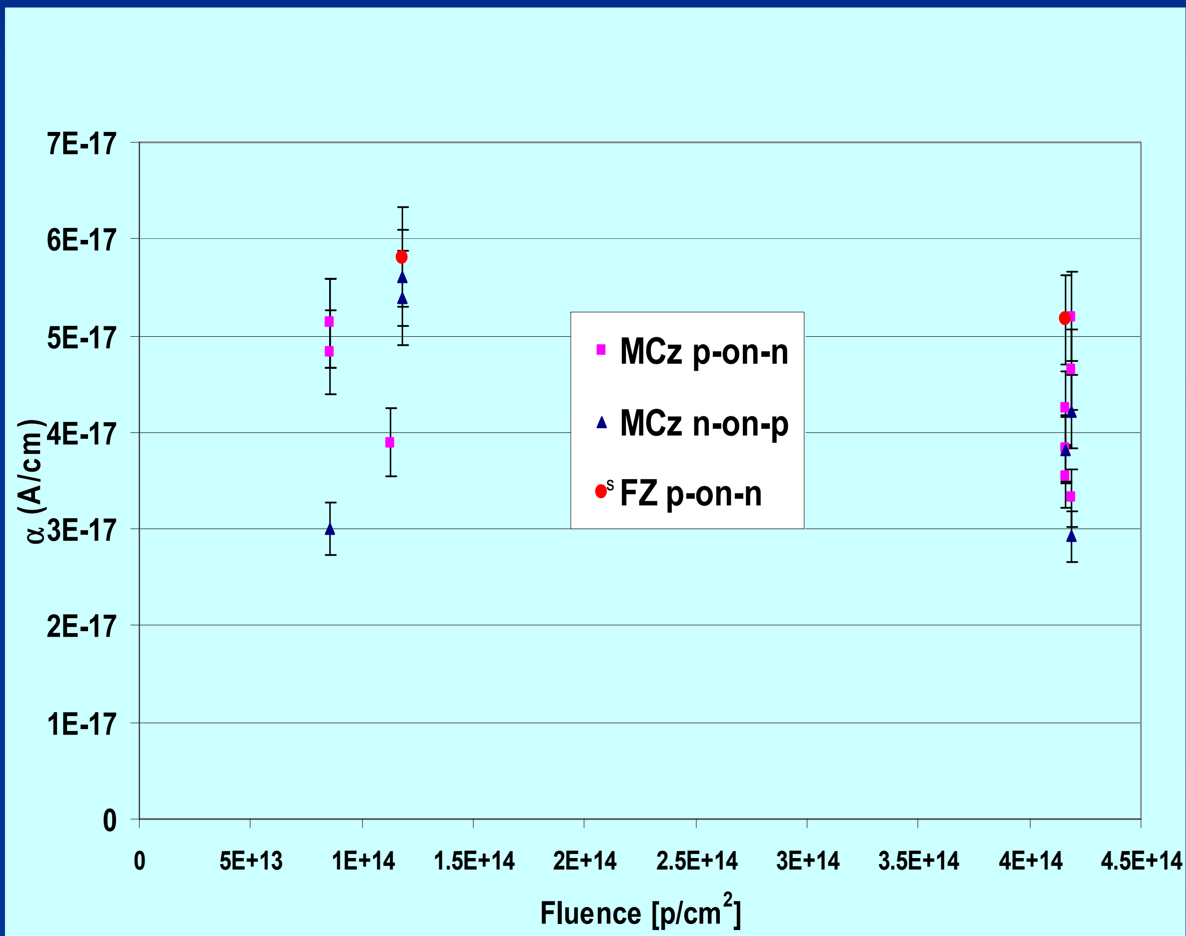
❖ Neff dependence on fluence calculated after full beneficial annealing

Measurements on the structures irradiated **at a fluence of 1.0 E+14 and 4.4 E+14 p cm-2**

All results are preliminary!

Parameter α - MCz p and n-type

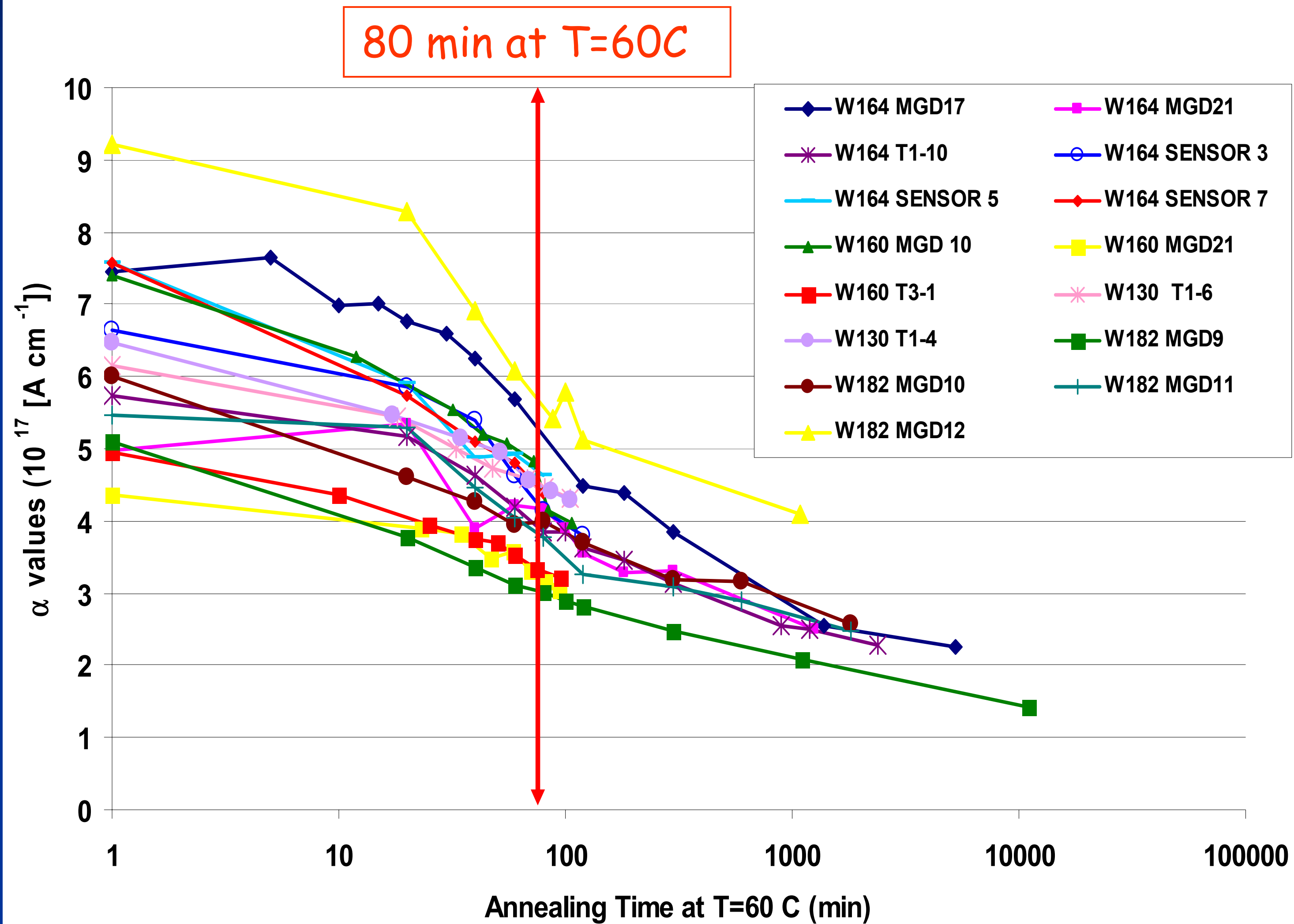
- Alpha parameter calculated with currents at depletion voltage +50V, at T=20°C (or with currents at T=0°C normalized to T=20°C) , after 8 minutes at $T_{annealing}$=80°C or 80 minutes at $T_{annealing}$=60°C



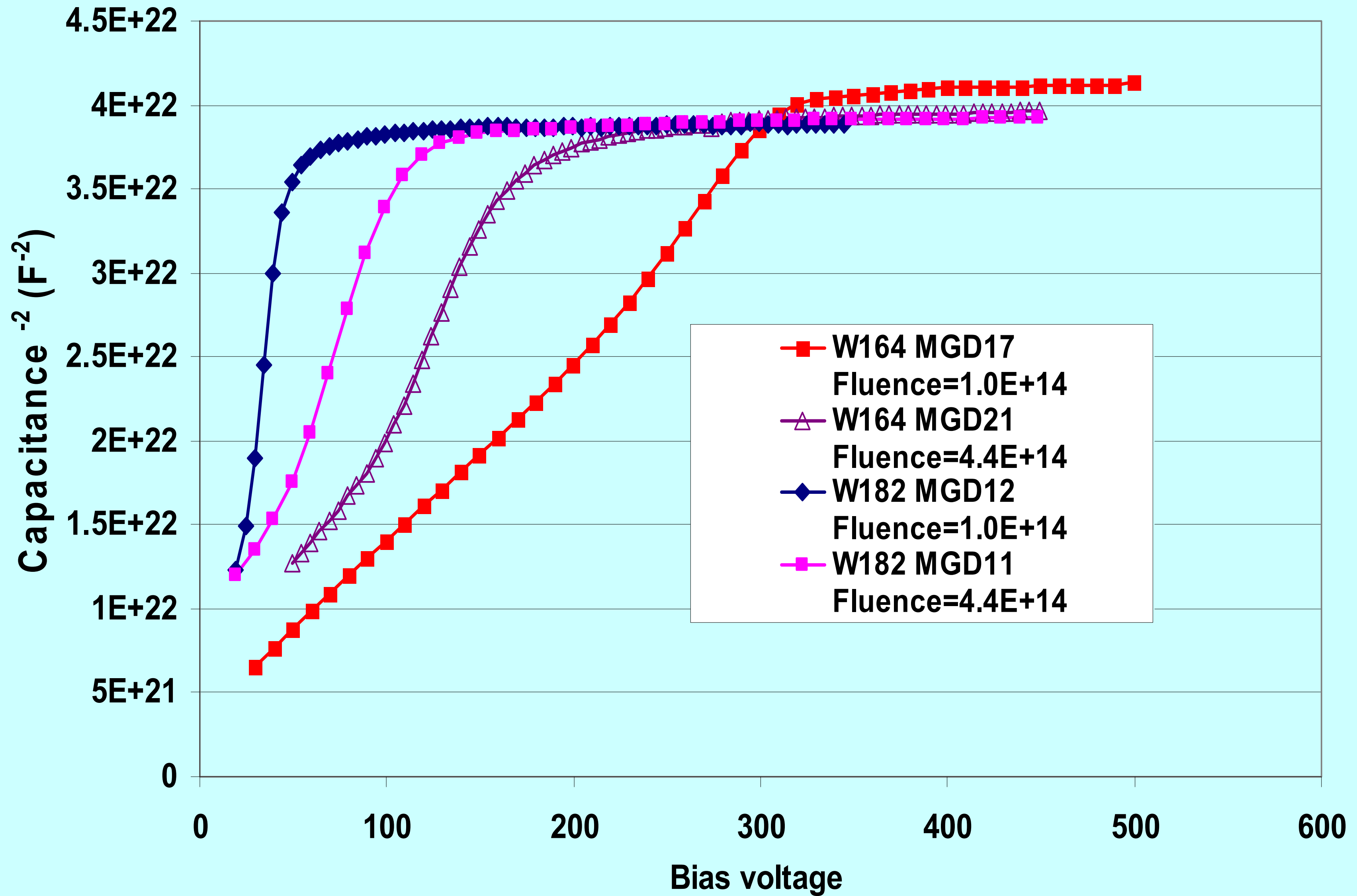
Average MCz p-on-n= 4.37E-17 A/cm

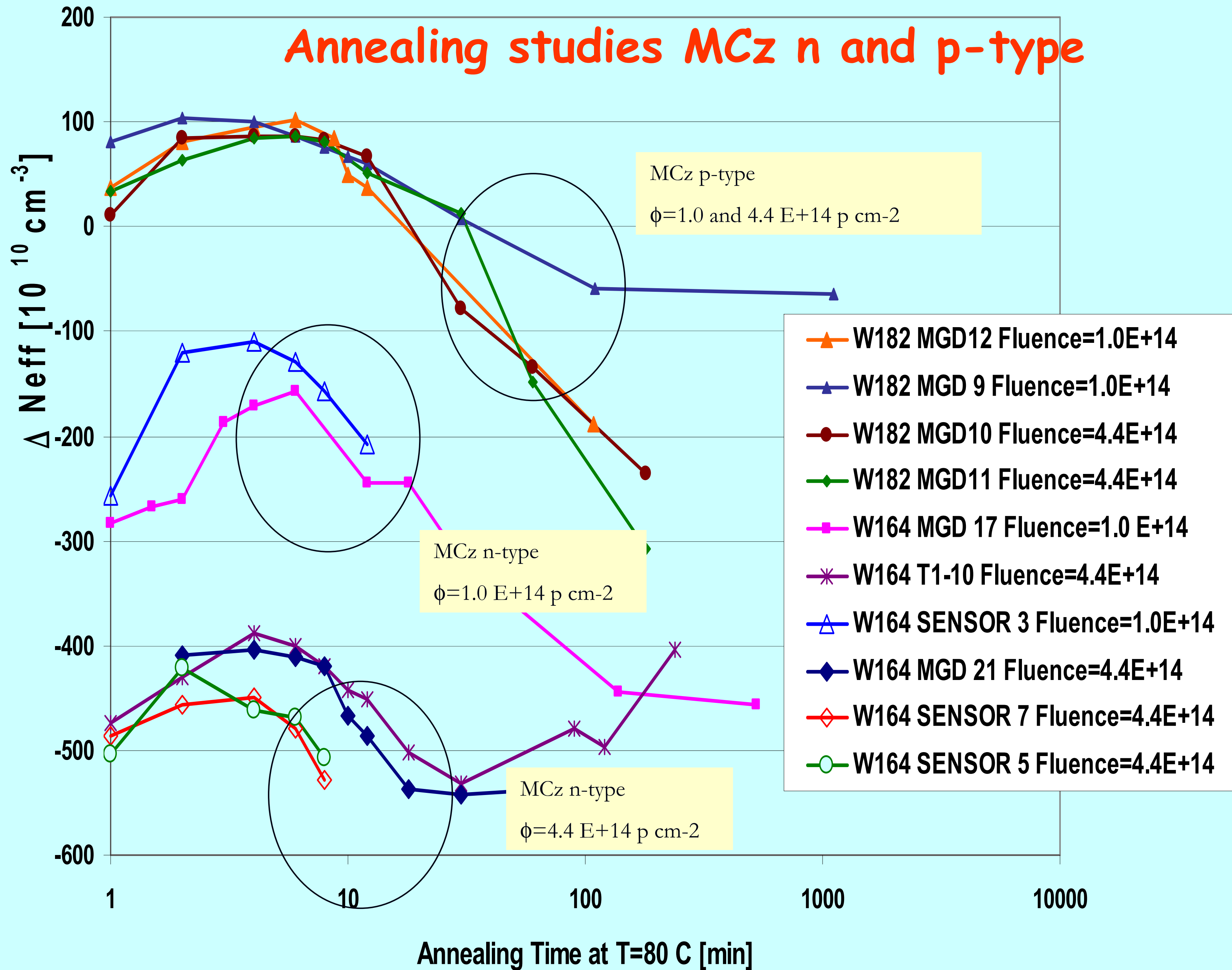
Average MCz n-on-p= 4.16E-17 A/cm

α Annealing MCz p and n-type



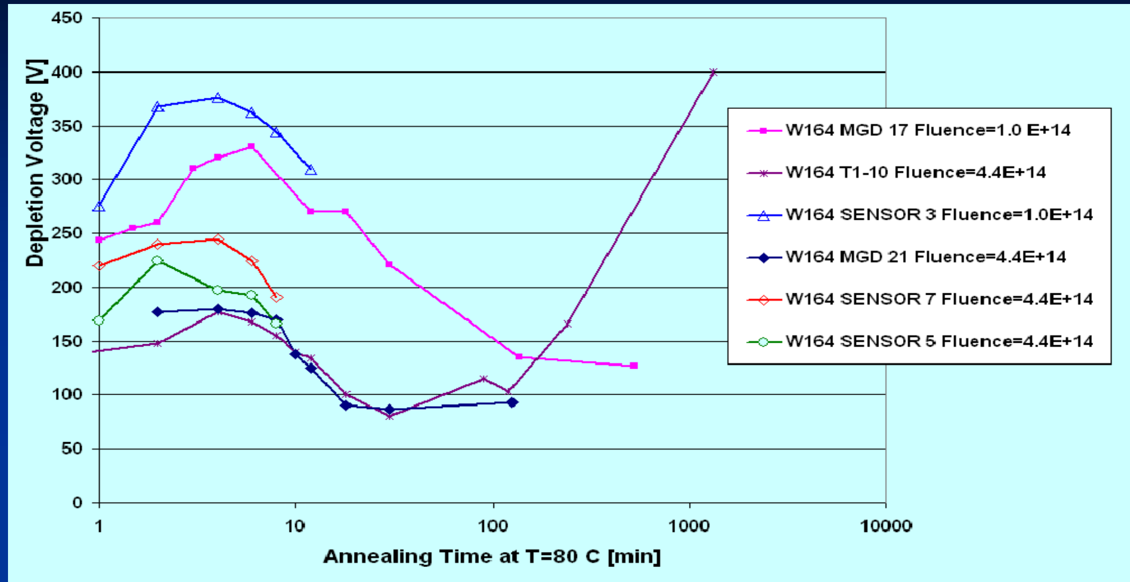
Examples of CV curves on MCz diode after irradiation





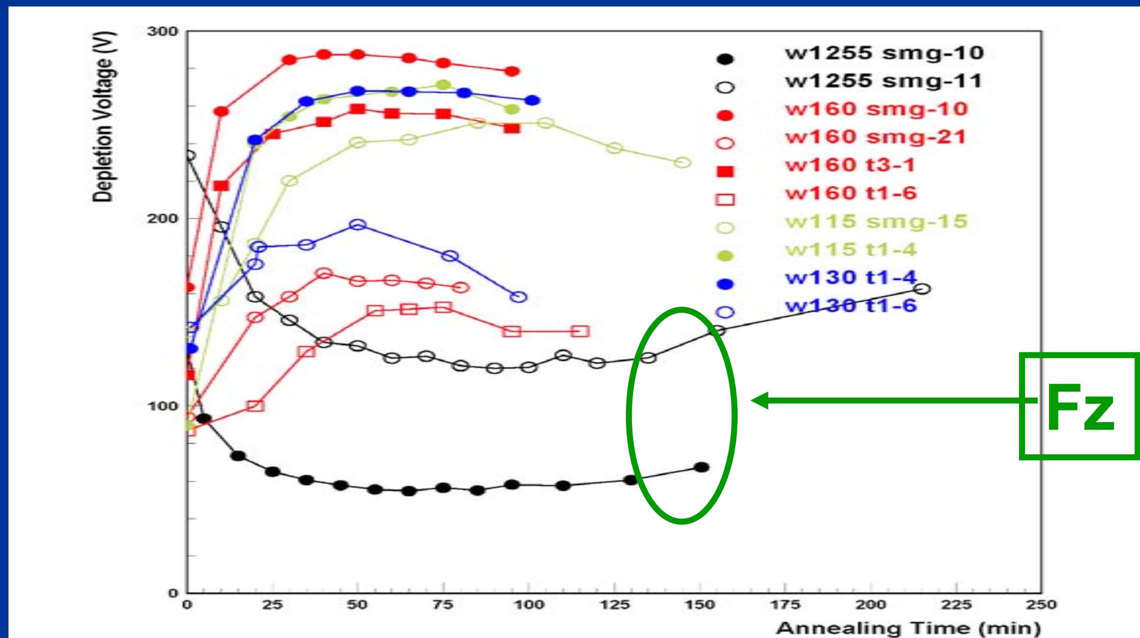
Annealing studies MCz n and p-type
MCz p-type
ϕ=1.0 and 4.4 E+14 p cm-2
MCz n-type
ϕ=1.0 E+14 p cm-2
MCz n-type
ϕ=4.4 E+14 p cm-2
W182 MGD12 Fluence=1.0E+14
W182 MGD 9 Fluence=1.0E+14
W182 MGD10 Fluence=4.4E+14
W182 MGD11 Fluence=4.4E+14
W164 MGD 17 Fluence=1.0 E+14
W164 T1-10 Fluence=4.4E+14
W164 SENSOR 3 Fluence=1.0E+14
W164 MGD 21 Fluence=4.4E+14
W164 SENSOR 7 Fluence=4.4E+14
W164 SENSOR 5 Fluence=4.4E+14
Δ Neff [10 10 cm -3]
Annealing Time at T=80 C [min]
200
100
0
-100
-200
-300
-400
-500
-600
1
10
100
1000
10000

Annealing studies (Vdepl) MCz n-type



W164 MCz n-type

Annealing at T=80°C



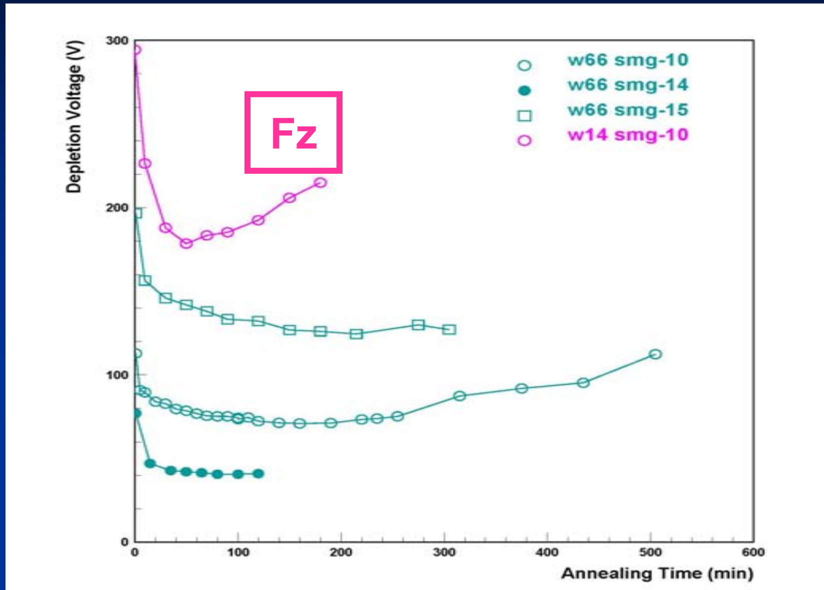
Fz and MCz n-type

Annealing at T= 60°C

● = 1.0 E+14 p cm^{-2}

○ = 4.4 E+14 p cm^{-2}

Annealing studies (Vdepl) MCz and Fz p-type

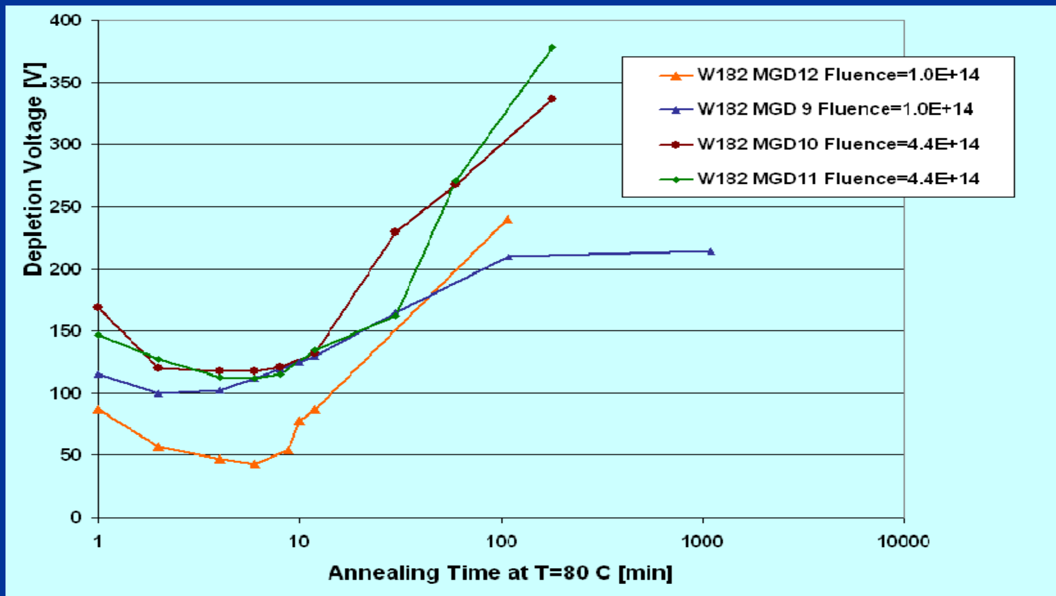


Fz and MCz p-type

Annealing at T= 60°C

● = 1.0 E+14 p cm^{-2}

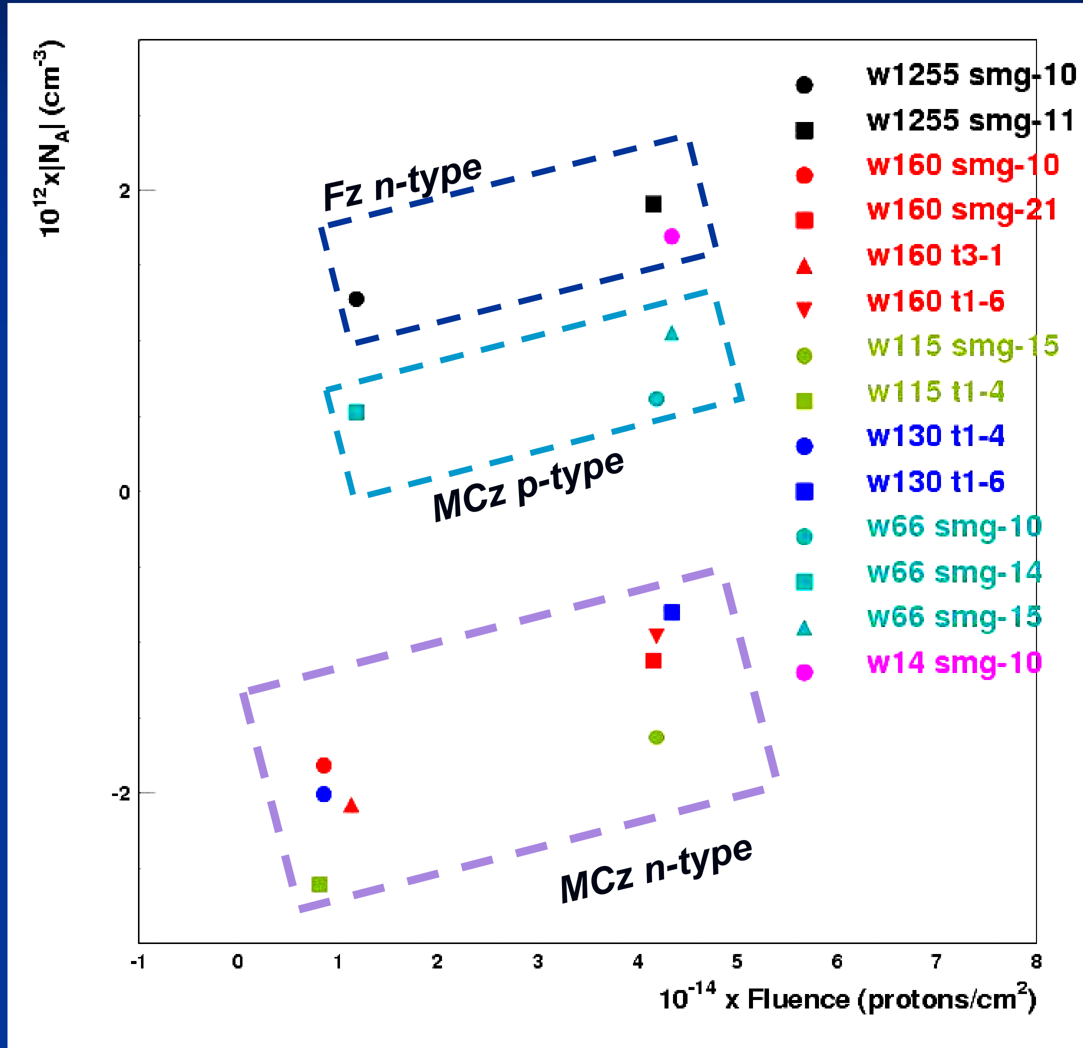
○ = 4.4 E+14 p cm^{-2}

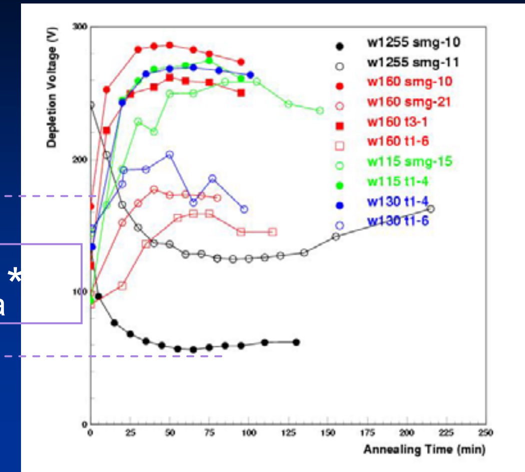


W182 MCz p-type

Annealing at T=80°C

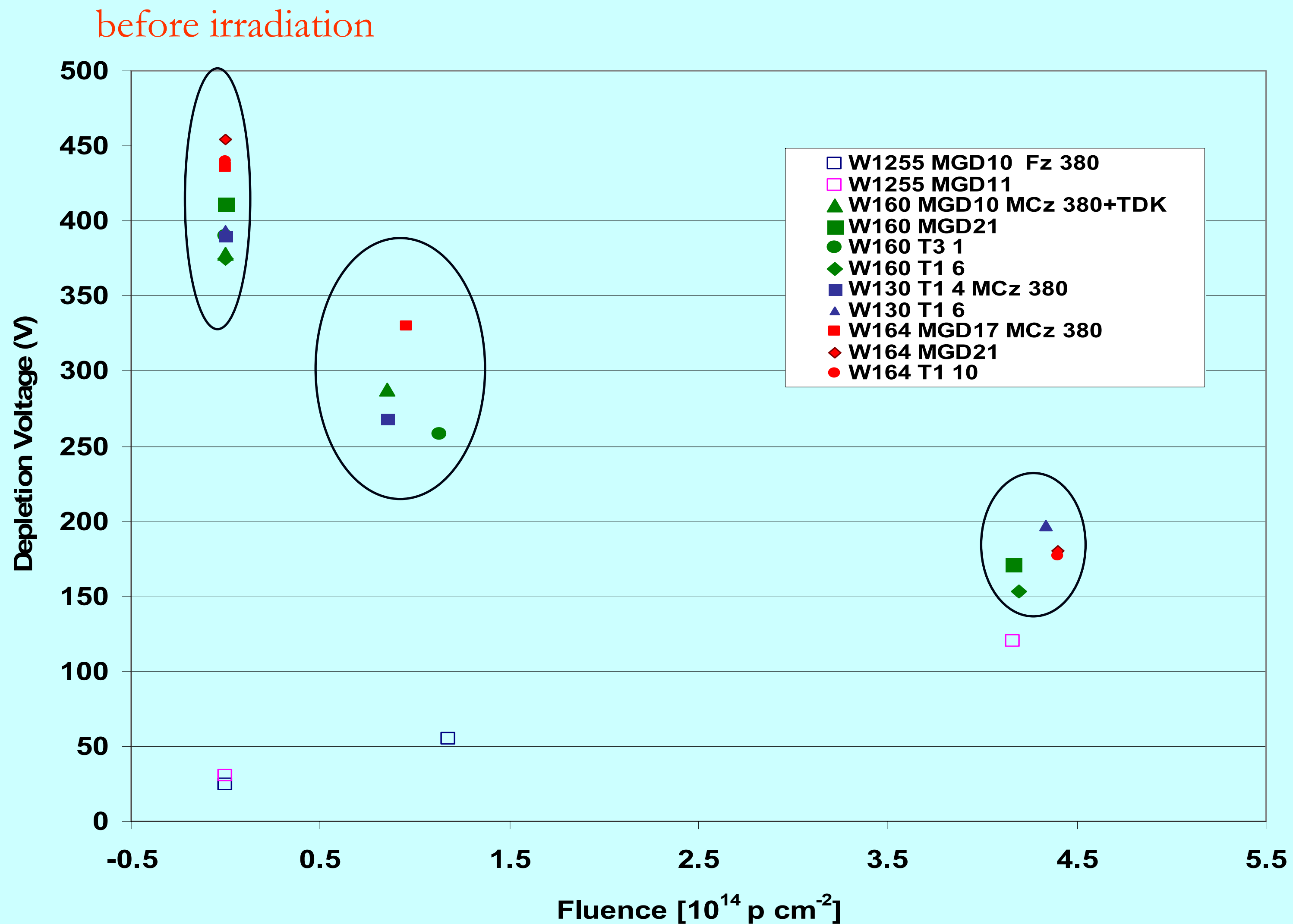
Na : beneficial annealed fraction





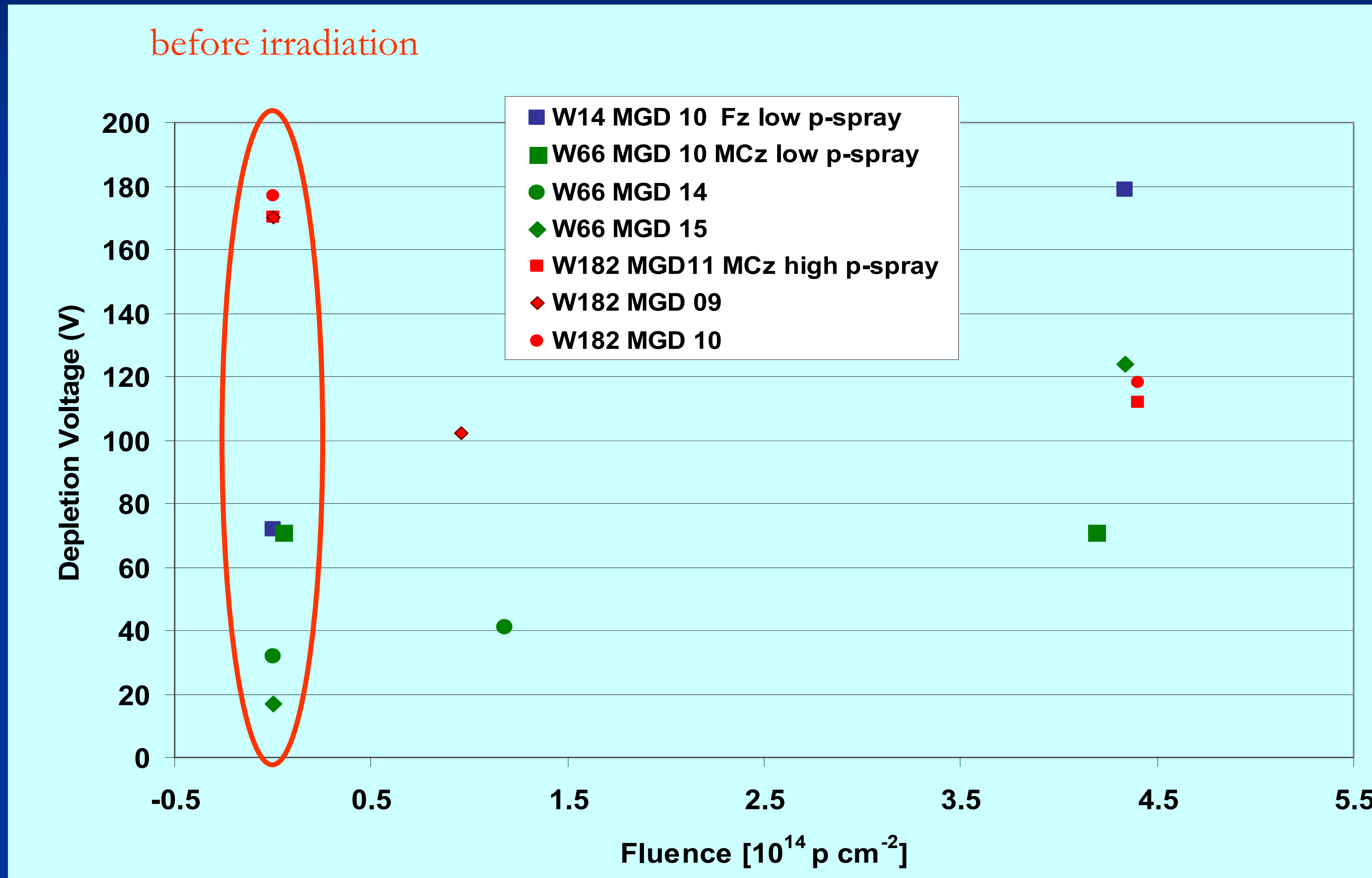
Depletion Voltage after full beneficial annealing

MCz and Fz p-on-n

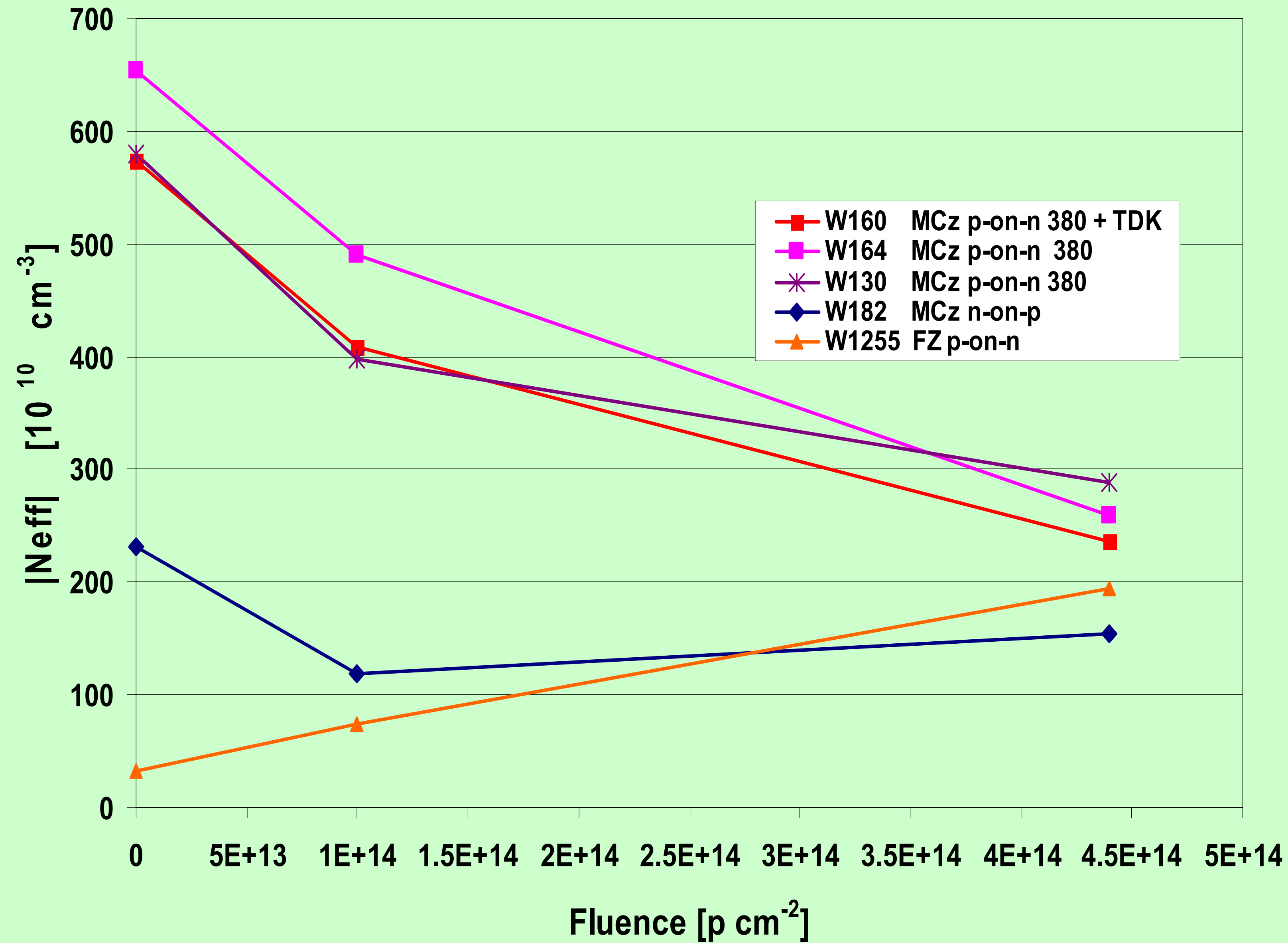


Depletion Voltage after full beneficial annealing

MCz and Fz n-on-p



Neff variation with fluence



Studies on mini-sensors

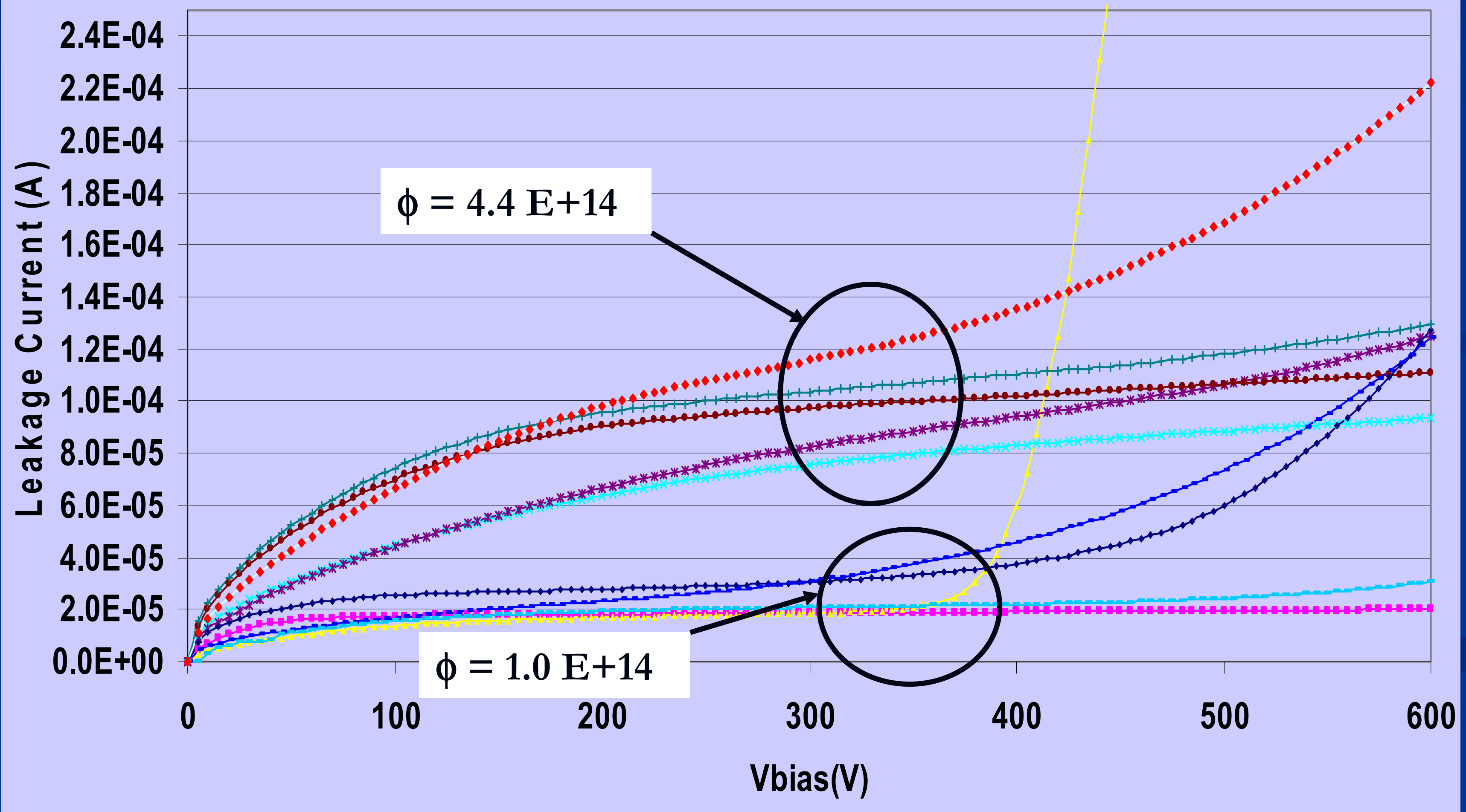
- Leakage current after irradiation as expected from the studies on the diodes of the same wafer
- Neff annealing follows behaviour observed on diodes
- Moderate increase of inter-strip capacitance after irradiation

IV on mini-sensors

f3= 1.0 E+14 p cm^{-2}

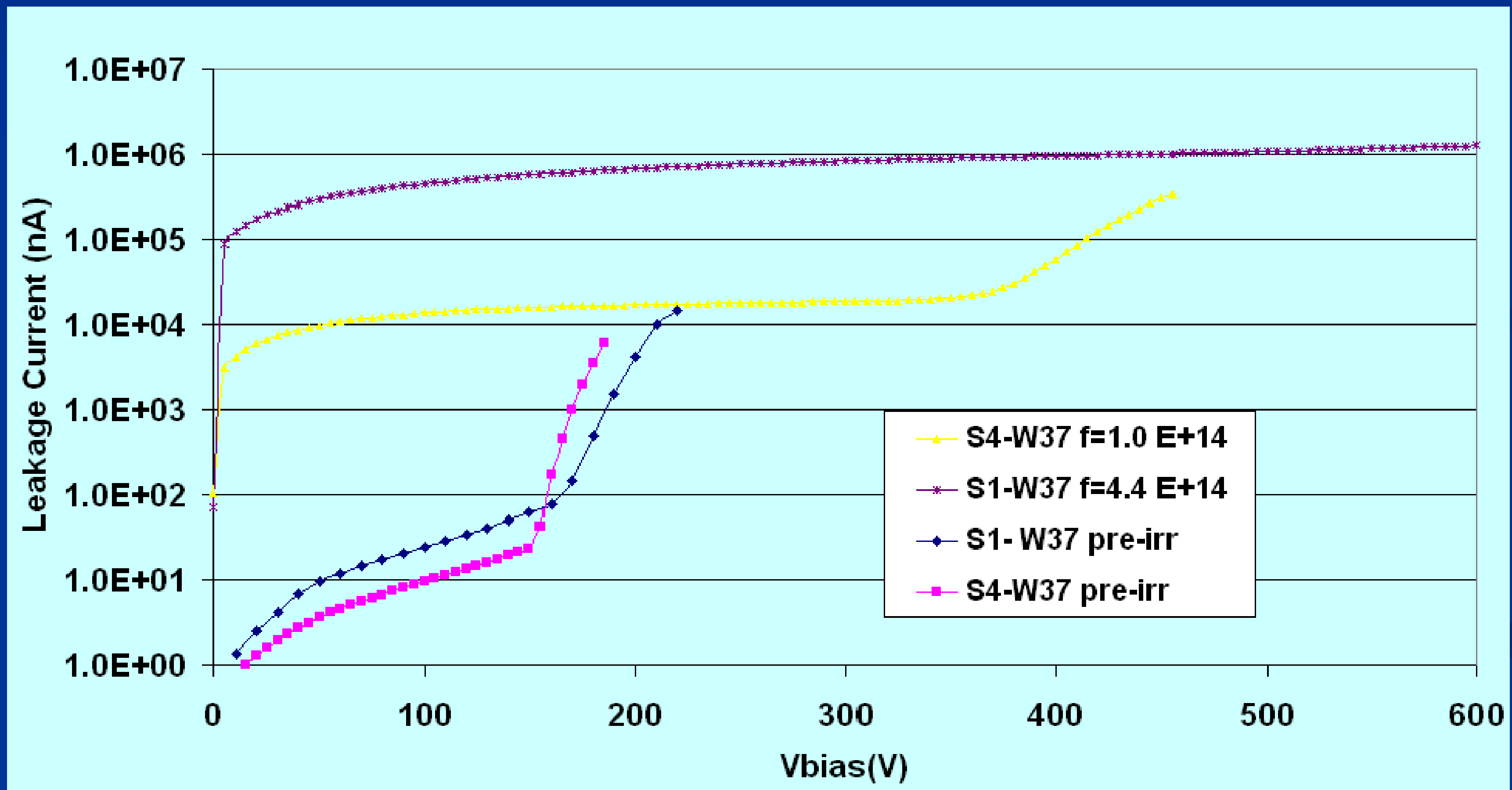
f2= 4.4 E+14 p cm^{-2}

s2-66 MCz(p) f3 | s4-w37 MCz(p) f3 | s1-14 MCz(p) f2 | s1-37 MCz(p) f2 | s1-66 MCz(p) f2
s1-w1255 Fz(n) f3 | s3-w115 MCz(n) f3 | s4-115 MCz(n) f3 | s1-w160 MCz(n) f3 | s7-w130 MCz(n) f2

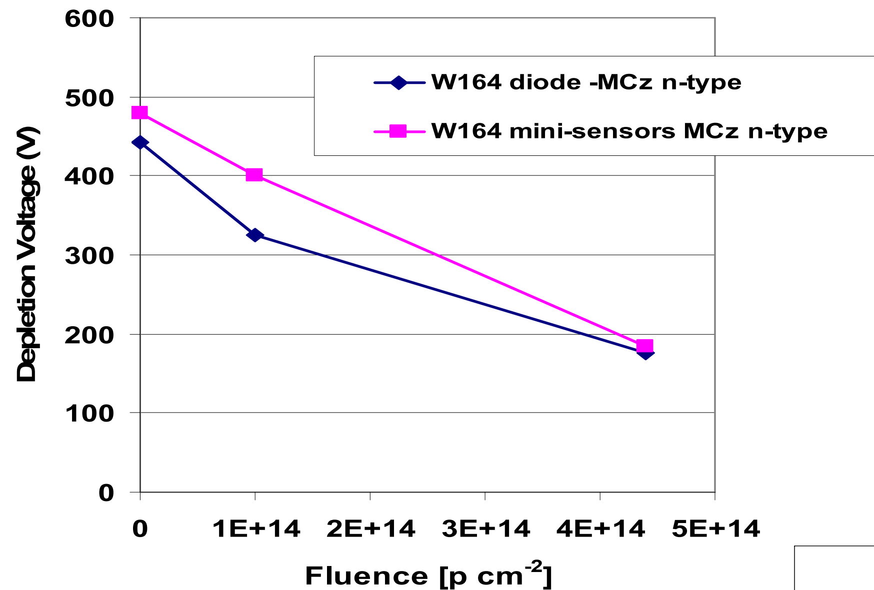


Fz W37 – n-on-p mini-sensors High p-spray

Breakdown voltage after irradiation is higher than before irradiation for the same mini-sensors



Variation of the depletion voltage with fluence

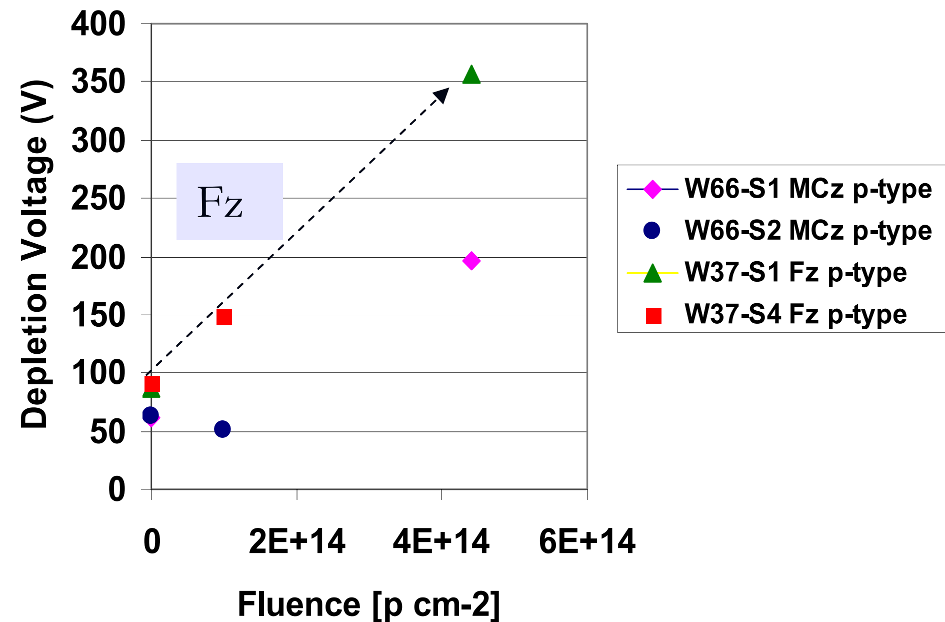


MCz n-type

Diodes and mini-sensors

MCz p-type

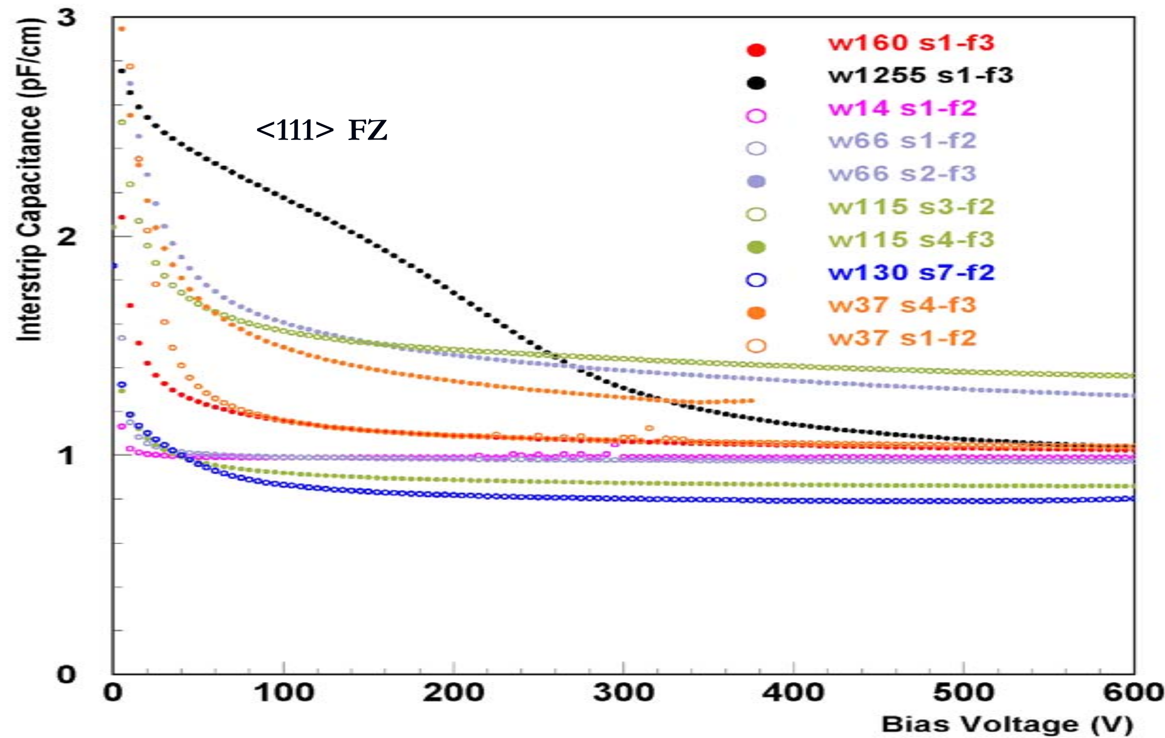
Mini-sensors



Inter-strip capacitance measured on mini-sensors

n-type MCz mini-sensors

	50 μm pitch	100 μm pitch
Pre-irradiated n-type	0.8 pF/cm	0.6 pF/cm
MCZ p and n-type ϕ= 1-4.4 E+14 p cm^{-2}	1.5-1.7 pF/cm	0.9-1.2 pF/cm

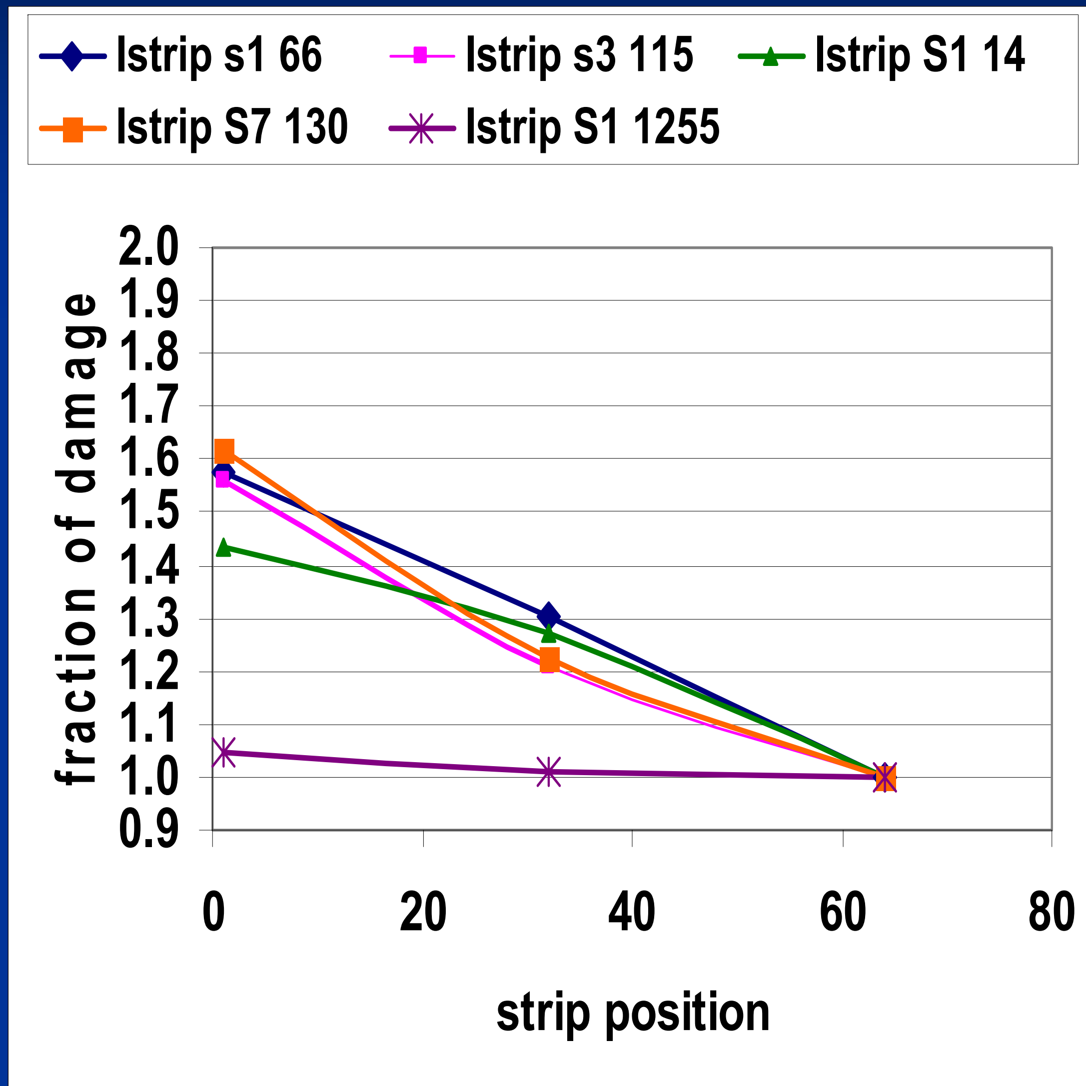


f3= 1.0 E+14 p cm^{-2}

f2= 4.4 E+14 p cm^{-2}

C-int decreases for the p-type sensors at increasing fluences. The opposite holds for the n-type sensors.

Strip leakage current in the mini-sensors



All the strip in the border and in the central region are functioning well.

The current level depends on the position with respect to the beam that is not uniform.

Studies performed at Φ=5.6E+15 p cm^{-2}

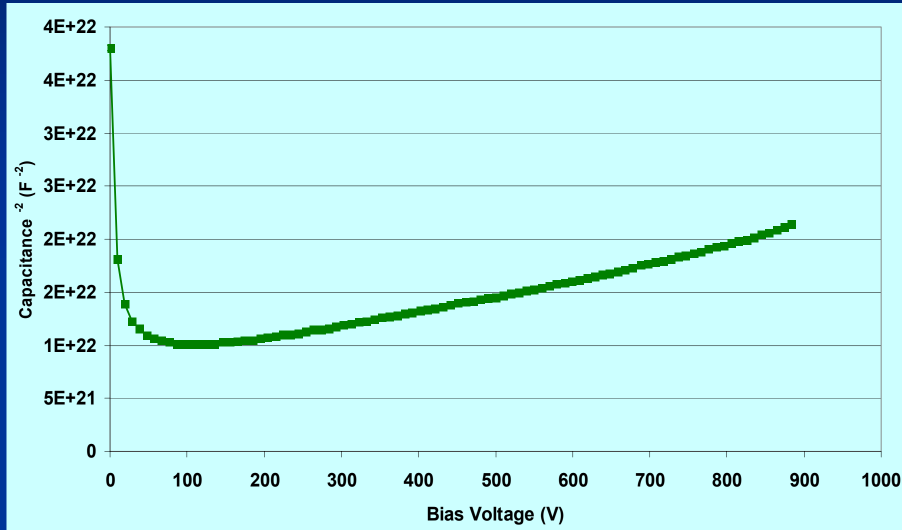
No clear depletion voltage found for n-type and p-type MCz diodes

- W164 MCz n-type: measured up to an annealing time of 34 min at T=80°C –
- W182 MCz p-type: up to an annealing time of 230 minutes at T=80 °C

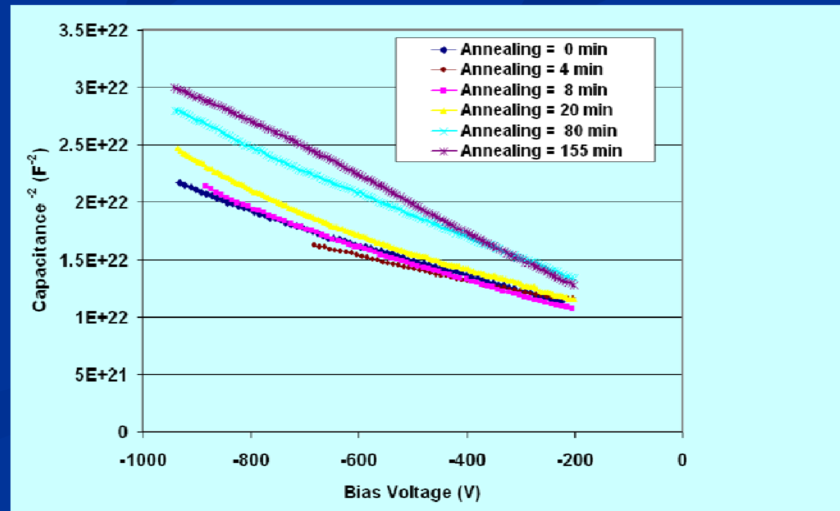
- Estimation of the depletion voltage from the slope of the CV curve after 4 minutes of annealing at T=80 °C: Vdepl>2000 V

MCz p-type - F=5.5E+15 p cm^{-2}

C^{-2}V W182 MGD01 annealing=8 min



Taking into account only the region where the bulk capacitance decrease a slight improvement is seen with annealing



Comments

- Pre-irradiation

1. MCz p-type wafers have a stronger resistivity spread than MCz n-type.
2. The performance of p-type mini-sensors need additional masks to implant the p-stop.
3. The n-type MCz mini-sensors perform comparably to the Fz ones.

- After-irradiation

1. Up to a fluence of 4.4 E+14 p cm^{-2} both p-type and n-type MCz material have comparable depletion voltages (additional fluence points are needed to draw clearer conclusions).
2. p-type mini-sensors show an improved IV after irradiation with p-spray.
3. Fairly good overall performance of all irradiated mini-sensors with good inter-strip capacitance.

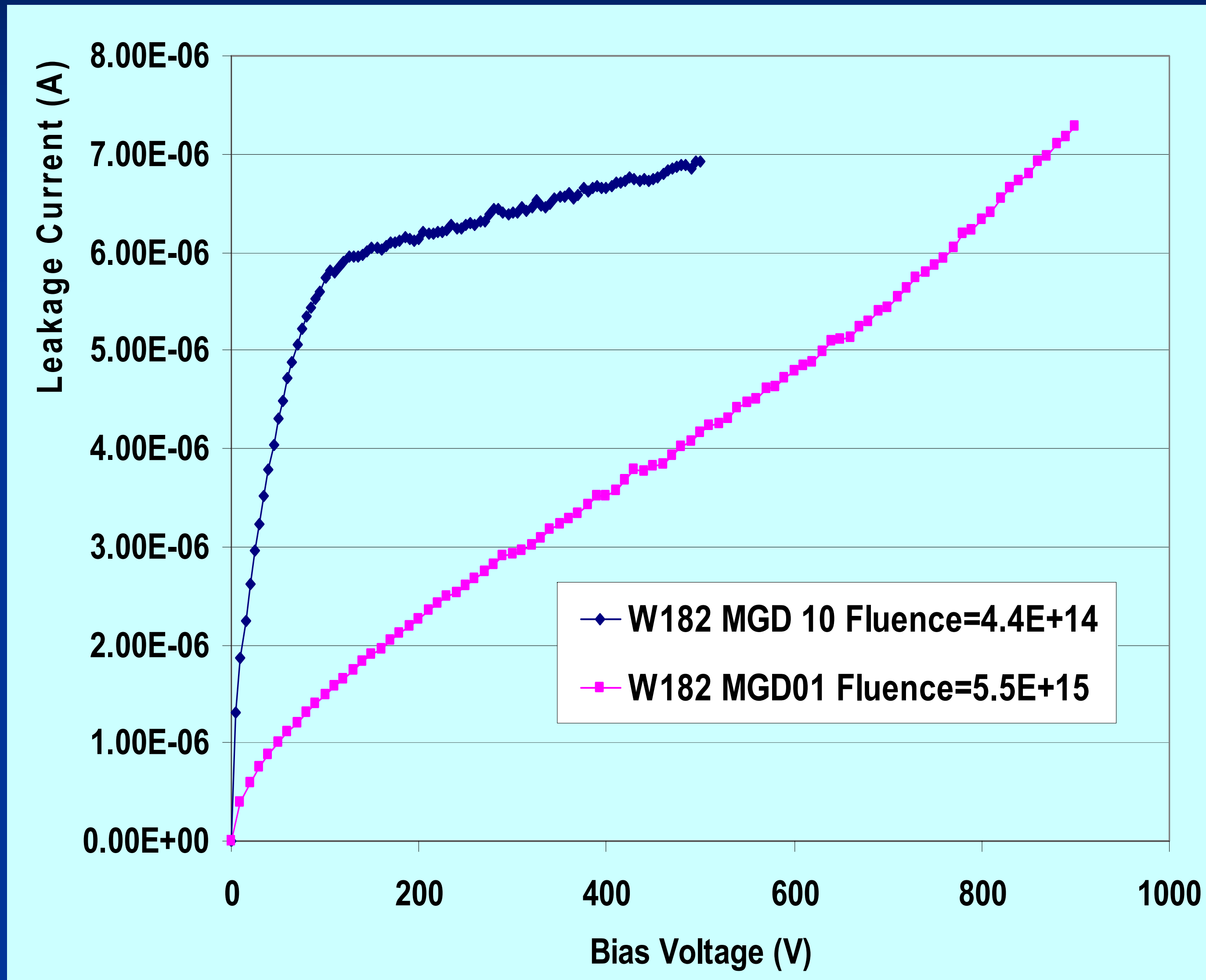
Future plans

- ✓ Increase measured sample (mini-sensors)
- ✓ Detailed study of higher fluence radiation effect
- ✓ Irradiate other n and p-type MCz structures with 26 Mev Protons in Karlsruhe, especially at fluences around 1E+15 p cm^{-2} and with neutrons in Liubiana
- ✓ CCE Measurements

1. Laser & β source/spectrometer system equipped
2. Few hybrid (CMS tracker) available
3. DAQ system (40 MHz) set-up and running

Next slides are BACK-UP

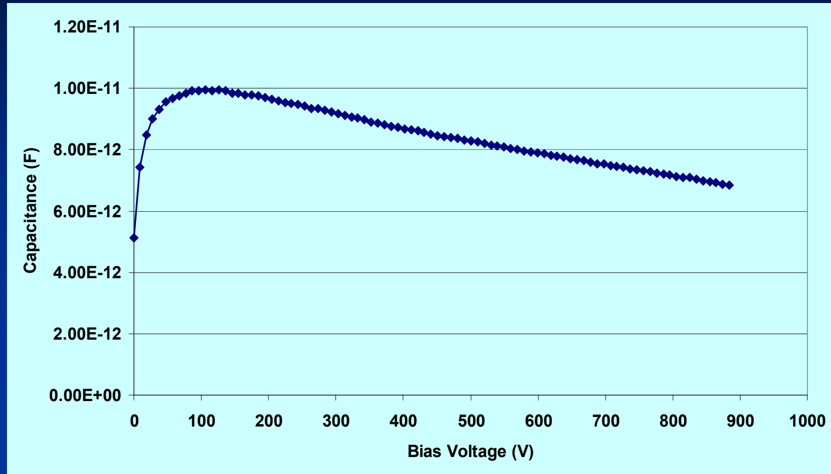
Comparison between leakage currents at two fluence point



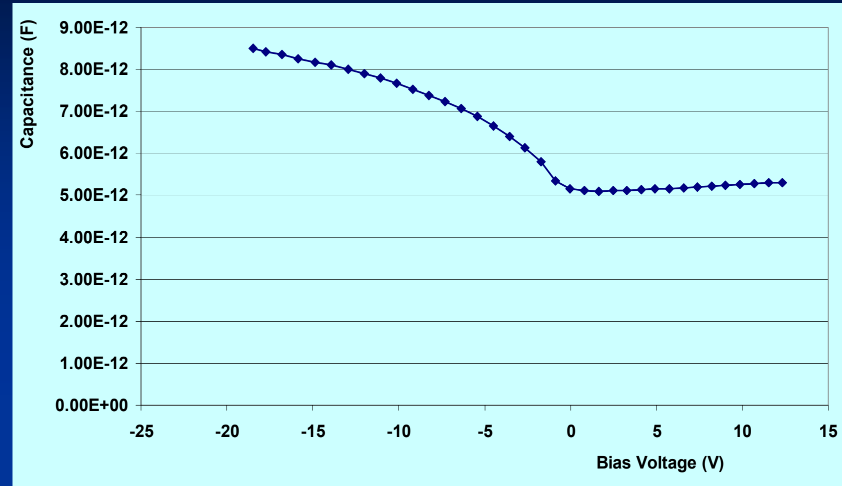
Currents of W182 MGD01 has been divided by the fluence ratio

MCz p-type - Φ=5.5E+15 p cm^{-2}

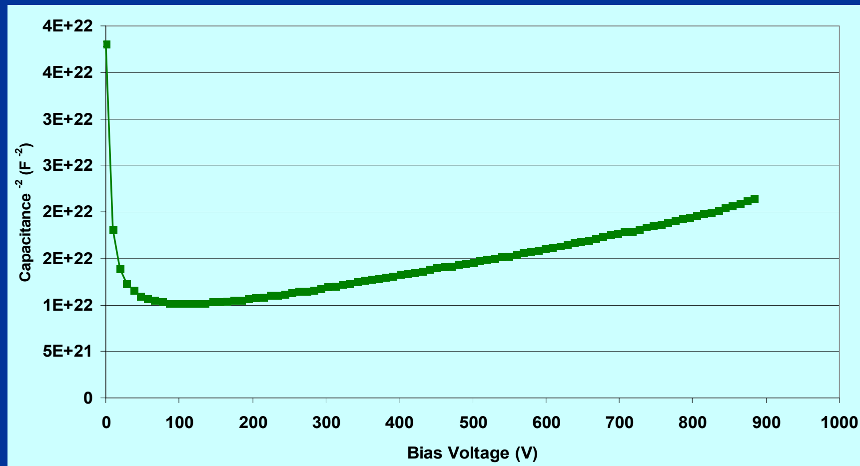
CV W182 MGD01 annealing=8 min



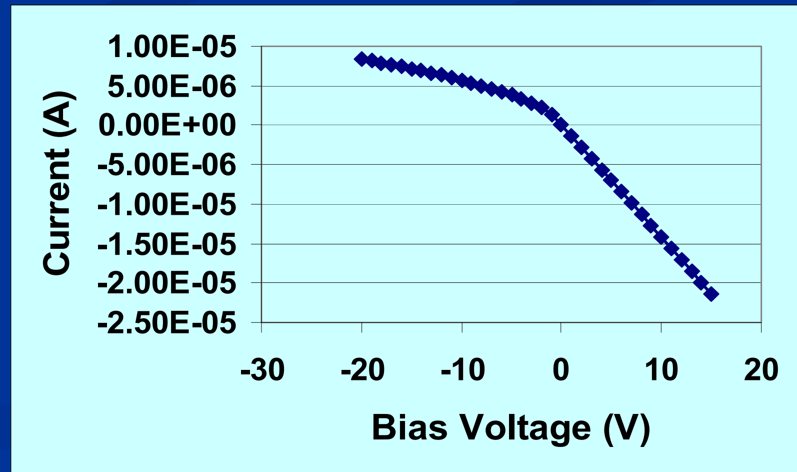
CV W182 MGD01 around Vbias=0



C^{-2}V W182 MGD01 annealing=8 min



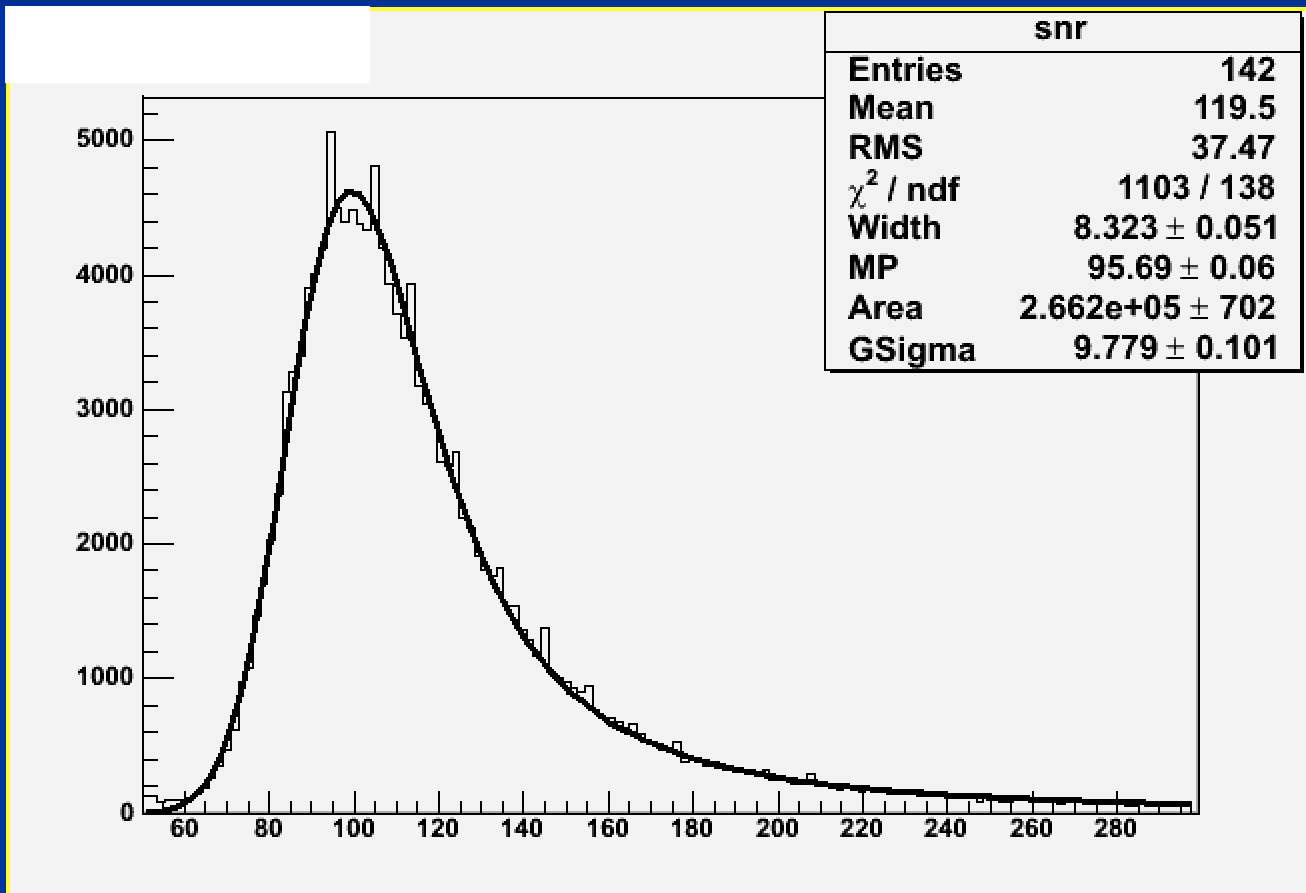
IV W182 MGD01 around Vbias=0



Measurement of the Charge Collection efficiency on a MCZ n-on-p MG diode

W160 MCz380+no LTO + TD killing

- Florence CCE set-up for single channel devices (thanks to S. Sciortino)
- Measurement done before irradiation

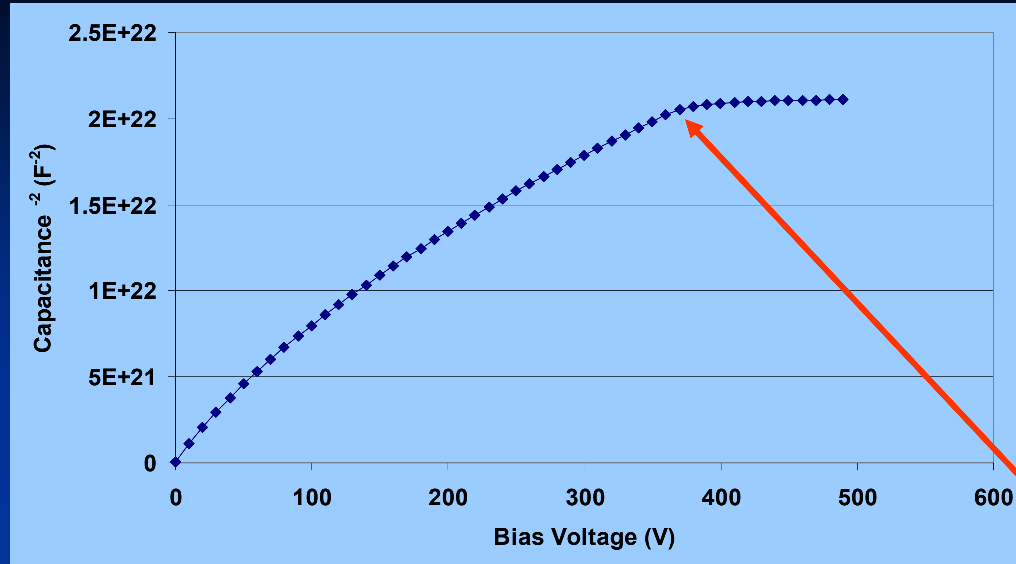


Convolution of a landau and a gaussian functions to extract the average energy loss

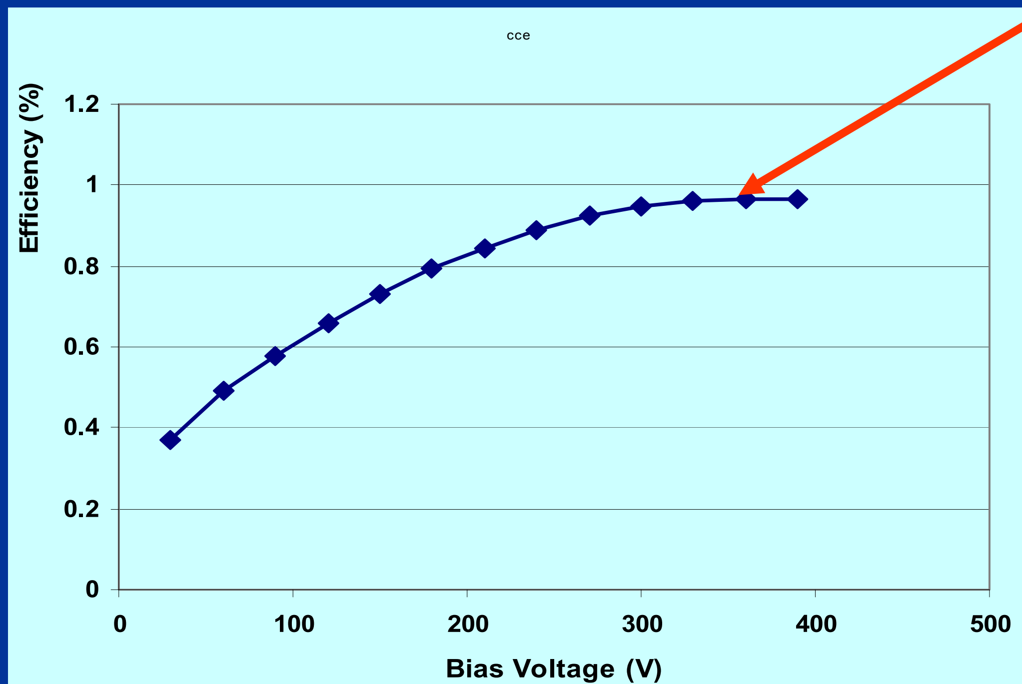
Calibration factor e/mV=218.9

e / μm = 89

C-V curve on the diode



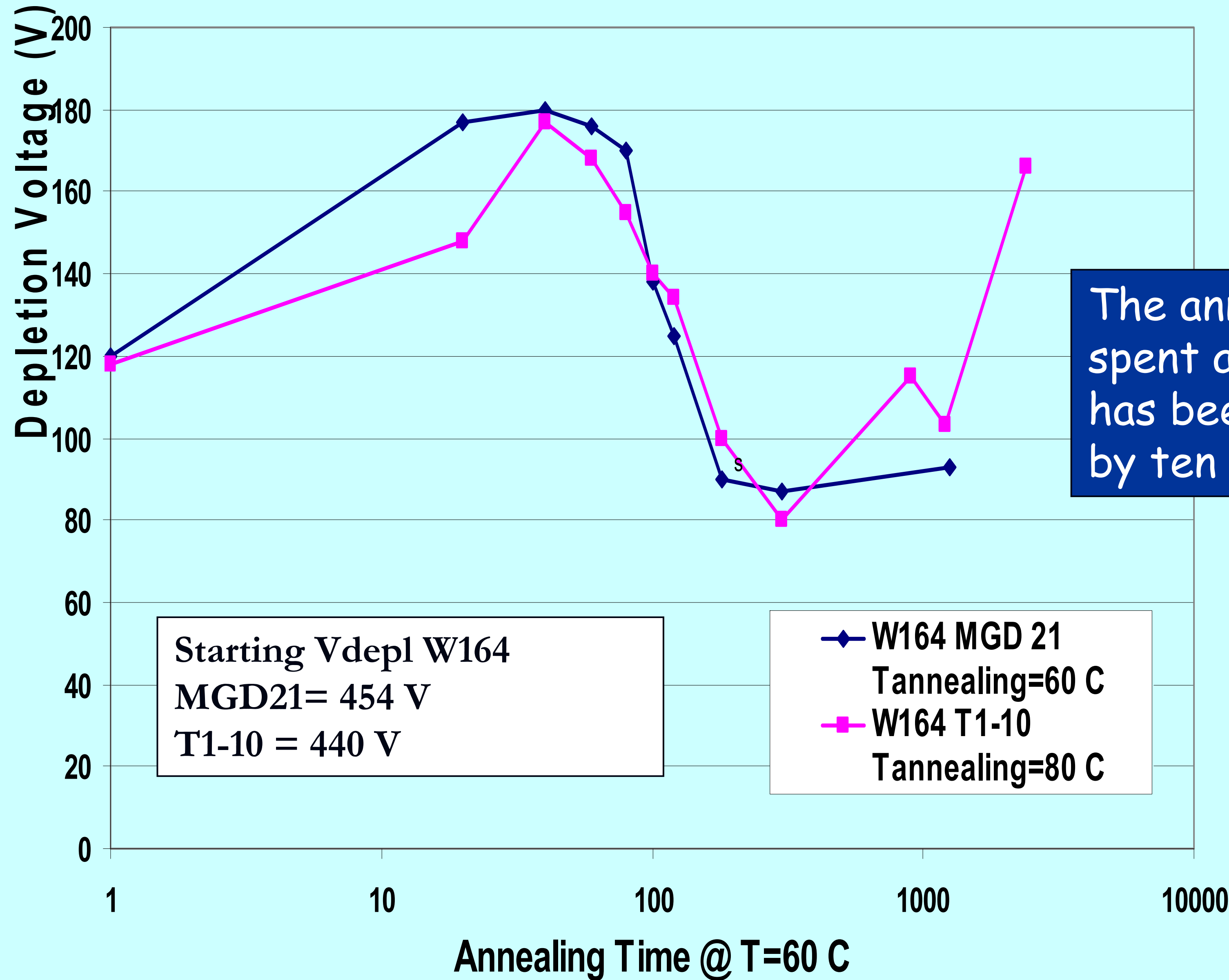
CCE before irradiation



At V=Vdepl (measured with a CV curve on the diode) the effective thickness for charge collection corresponds to practically all the physical thickness of the wafer

Comparison between annealing at T=60°C and T=80°C

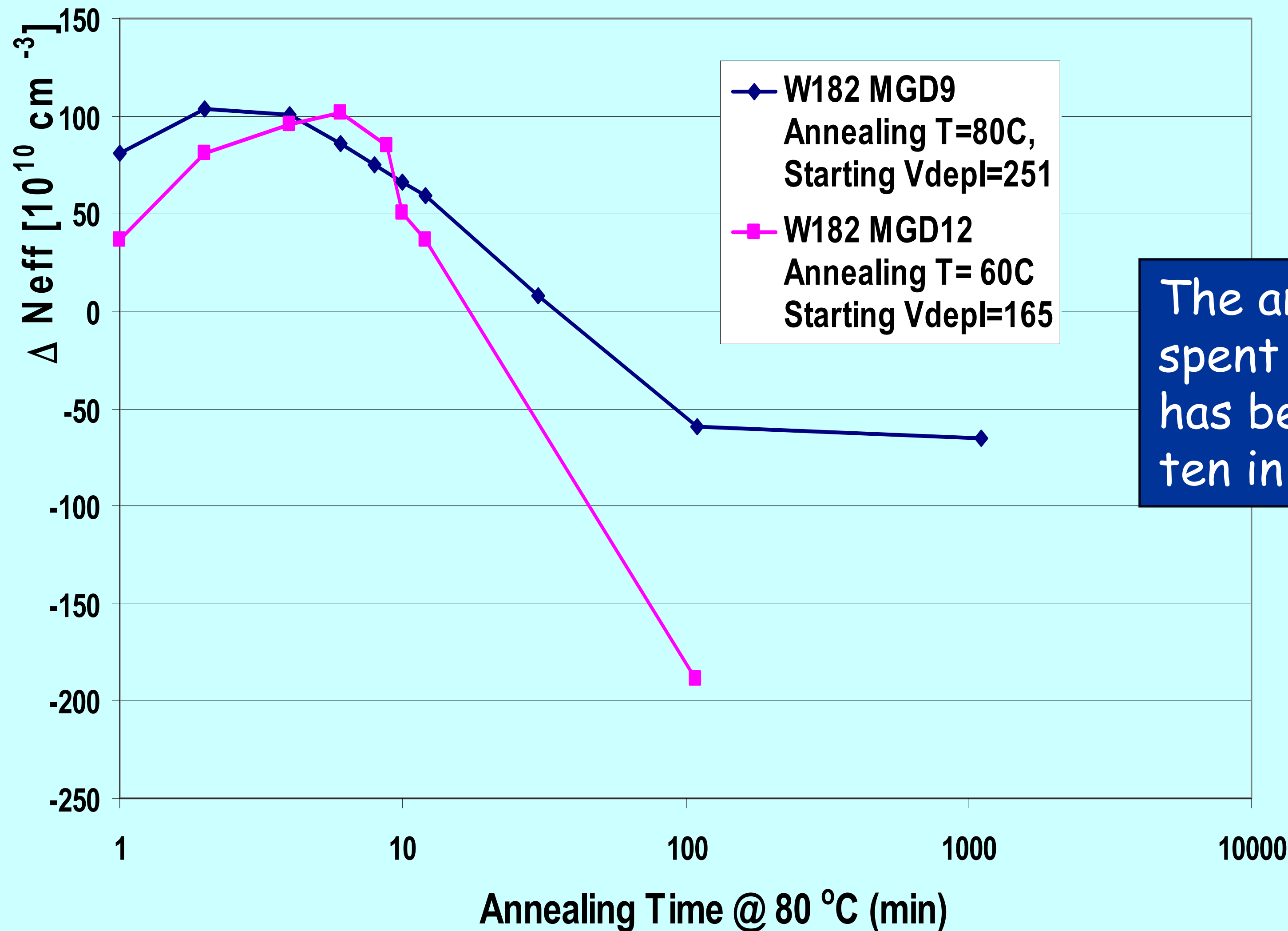
Wafer 164 ϕ= 4.4 E+14 p cm^{-2}



The annealing time spent at T=80°C has been multiplied by ten in this plot

Comparison between annealing at T=60°C and T=80°C

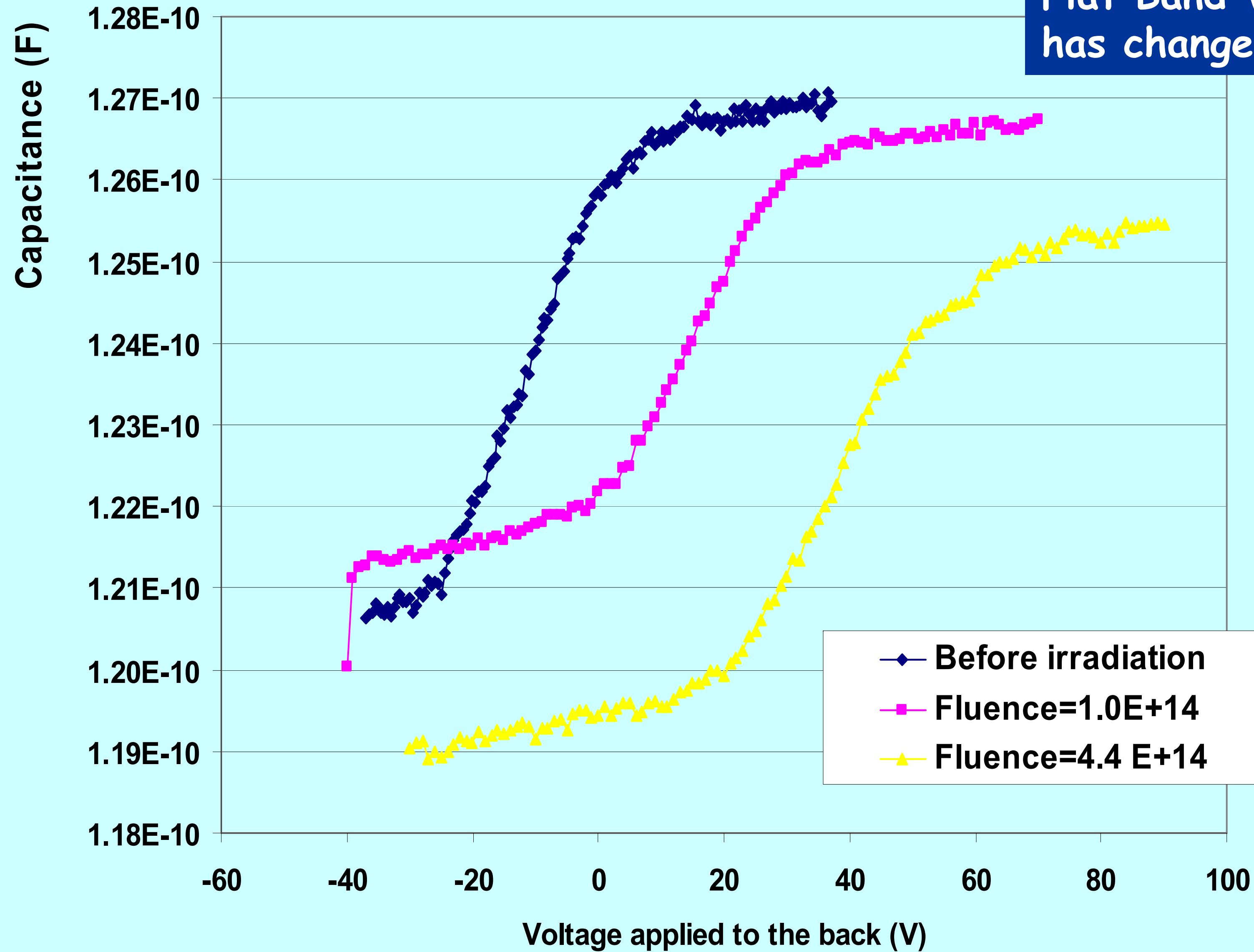
Wafer 182 ϕ= 4.4 E+14 p cm^{-2}



The annealing time spent at T=60°C has been divided by ten in this plot

CV on MOS MCZ n-on-p - High dose p-spray

f=100 Hz



Flat Band Voltage has changed sign