Study of radiation damage induced by 26MeV protons and reactor neutrons on heavily irradiated MCz, FZ and Epi silicon detectors

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on behalf of the SMART Collaboration*

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External collaborators INFN Padova, Trieste & ITC-IRST Trento

- **Layout and materials of SMART detectors**
- **Post-irradiation measurements**
- **Analysis:** MCz n Inversion or Double Junction?
  CCE MCz p
  Epitaxial
  MOS – Interstirp Capacitance
- **Conclusions**

8th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders
PRAGUE, 25-28 June, 2006

Wafer Layout

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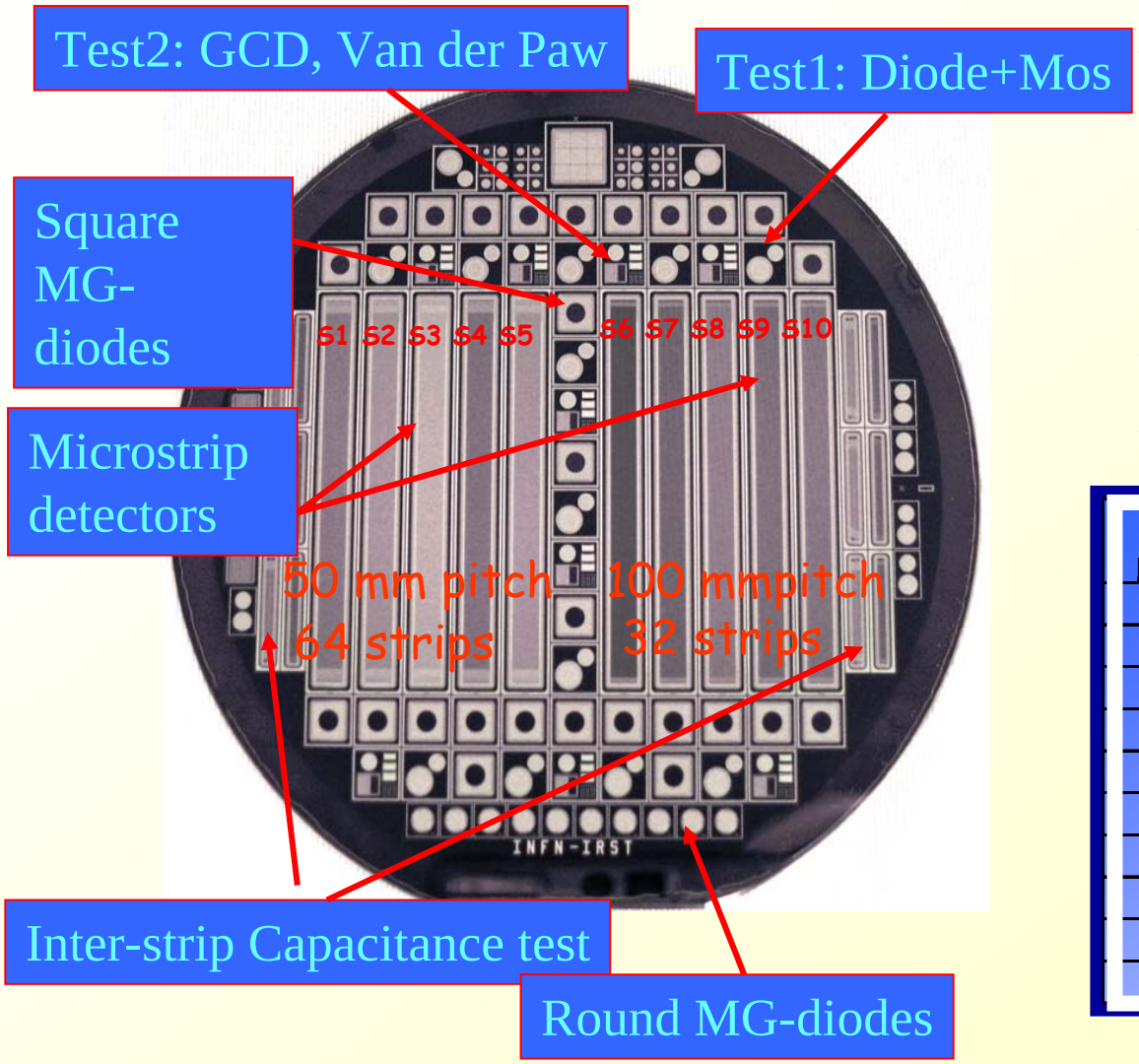

- ✓ RD50 common wafer procurement (produced by Okmetic - Vantaa, Finland)
- ✓ Wafer Layout designed by the SMART Collaboration
- ✓ Masks and process by ITC-IRST
- ✓ 10 different strip geometries

µ-strip #	pitch (µm)	p+ width (µm)	Metal width (µm)
S1	50	15	23
S2	50	20	28
S3	50	25	33
S4	50	15	19
S5	50	15	27
S6	100	15	23
S7	100	25	33
S8	100	35	43
S9	100	25	37
S10	100	25	41

PRODUCTION

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MCz Samples

RUN I
p-on-n
22 wafers

<100> ρ>500 Ω*cm thick=300μm

- ✓ Standard: LTO, sintering @ 420C
- ✓ no LTO (pass. layer), sint. @ 380C
- ✓ no LTO, sintering @ 350C
- ✓ no LTO, sintering @ 380C + TDK

Fz Samples

<111> ρ>6KΩ*cm th.=300μm

- ✓ Standard Process

Epi Samples

ρ≈500Ω*cm th.=150μm

RUN II
n-on-p
24 wafers

<100> ρ>1.8 KΩ*cm thick=300μm

- ✓ No over-glass passivation
- ✓ Low dose p-spray (3.0E12 cm^{-2})
- ✓ High dose p-spray (5.0E12 cm^{-2})

MCz Samples

<100> ρ>5KΩ*cm th.=200 mm

- ✓ Low dose p-spray (3.0E12 cm^{-2})
- ✓ High dose p-spray (5.0E12 cm^{-2})

Irradiation

April 2006

Irradiation with reactor neutrons in Ljubljana

12 fluences: 5.0×10^{13} 8.5×10^{15} 1-MeV n/cm^2

27 mini-sensors, 11 test structure (capts),100 diodes

60 % n-type, 40 % p-type

Thanks to V.Cindro and G.Kramberger

Set up for the irradiation @ JSI(Ljubljana)

June 2006

Irradiation with 26 MeV protons at the Cyclotron of the Forschungszentrum Karlsruhe

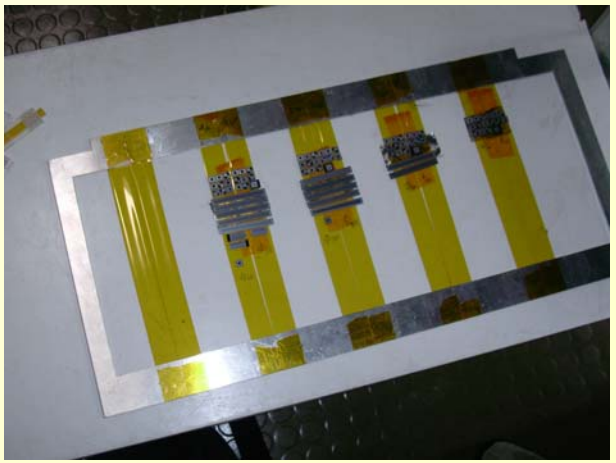
10 fluences: 1.2×10^{14} - 6×10^{15} 1-MeV n/cm^2

20 mini-sensors, 8 test structure(capts), 100 diodes

60 % n-type, 40 % p-type

Thanks to A. Furgeri

Set up for the irradiation @ FZK(Karlsruhe)



Post Irradiation Characterization

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- **On Diodes:**

  IV and CV measurements (@ 0 °C or 20 °C)

  - immediately after irradiation before annealing
  - repeated after annealing steps (@ 20, 60 or 80 °C)
  - Charge Collection Efficiency

  in order to:

  (1) follow the radiation damage evolution on bulk current and effective doping concentration;
  (2) determine the effective irradiation fluences
  (3) estimate the inversion and double junction fluence
  (4) test Vdep with charge collection to validate CV measurements and Determine Charge Collection Efficiency at full depletion

- **On Mos devices:**

  CV (@ 0 ^{0}C)

  - immediately after irradiation before annealing
  - repeated after annealing steps(@ 80 ^{0}C)

  in order to study:

  variation of the oxide charge as a function of the irradiation fluence in order to understand the behavior of the interstrip capacitans

Depletion voltage after irr. (Fz n Type inversion)

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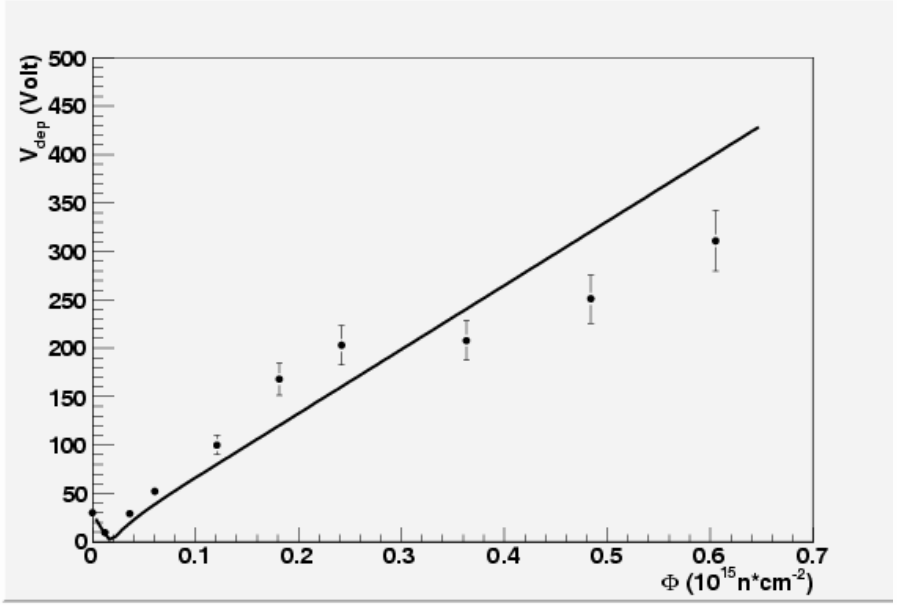
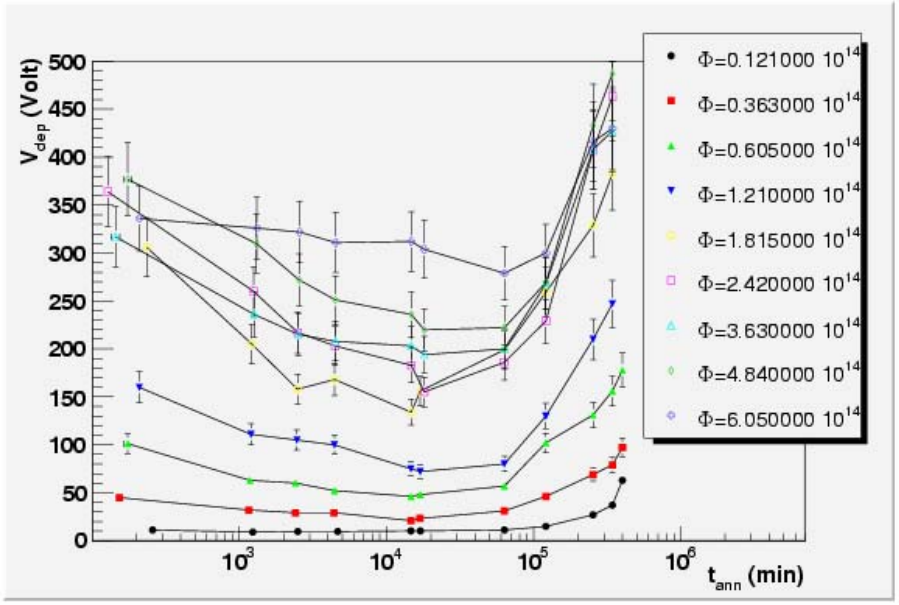
PROTON IRRADIATION

We are following annealing at room temperature

Typical behaviour for standard FZ_n





T=20^{0}C

Depletion voltage after irr. (MCz n Type inversion?)

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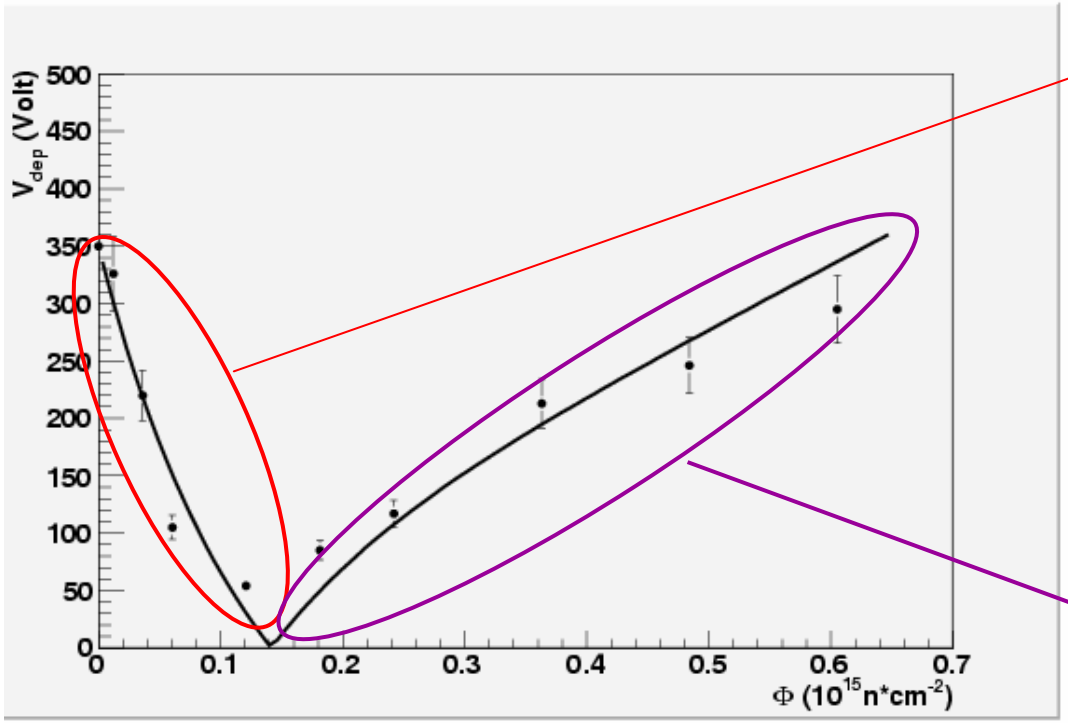
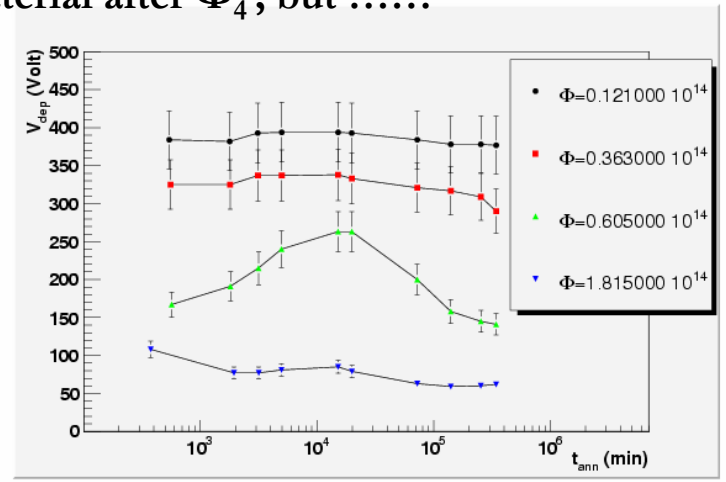
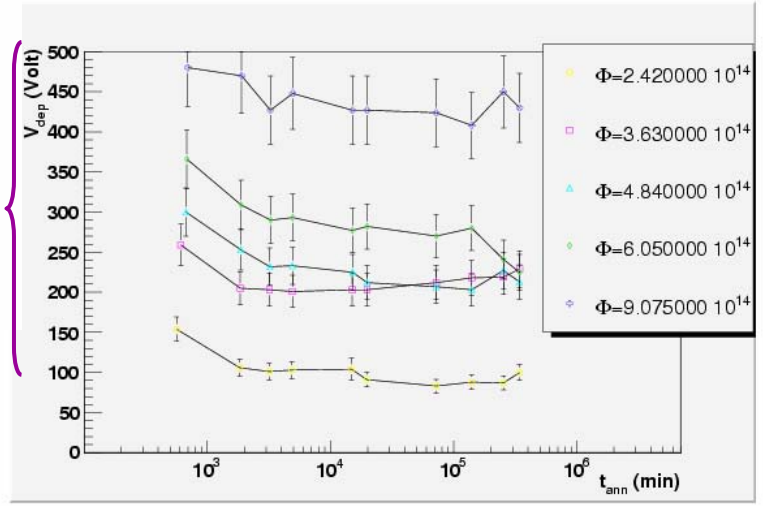
The annealing behaviour is typical of type inverted (p-type) material after Φ_4, but ……





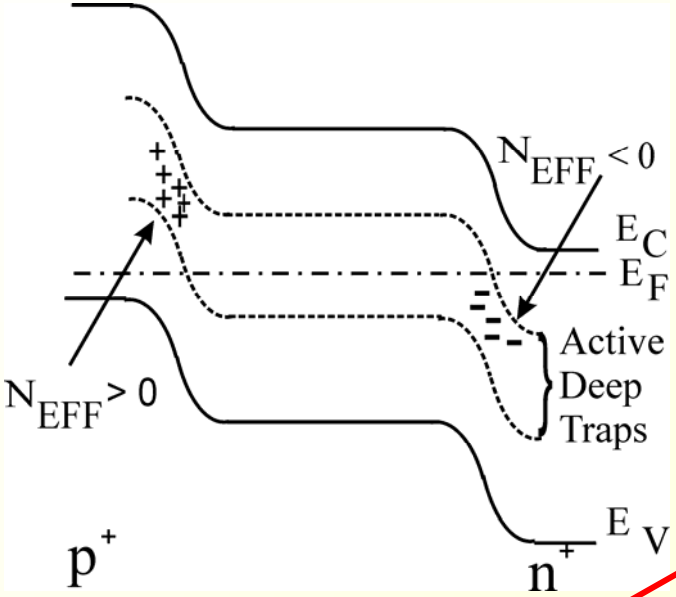
T=20°C



PROTON IRRADIATION

Double Junction (DJ) effect

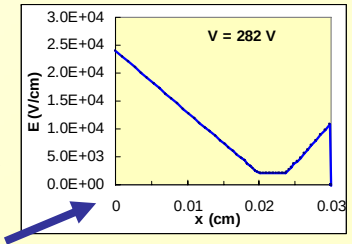
For very high fluences (of the order of 10^{14} n_{eq}/cm^2) a depletion region can be observed on both sides of the device for STFZ p^+/n diodes. In STFZ DJ arises after inversion. The opposite in MCz! This may explain $V_{dep}(\Phi,t)$ profiles.



- Double junction effect has been observed on MCz already **at** Φ = **3×10^{14}** n/cm^2
- At the fluence **$\Phi=1.3\times10^{15}$** n/cm^2 the dominant junction is still on the p^+ side

Strip readout side: no over depletion

p+ n+



Electric field extracted from fit - TCT data

No SCSI on MCz up to
$\Phi \sim 1.3\times10^{15}$ n_{eq}/cm^2
TCT measurements

Fake "SCSI" on MCz at $\Phi \sim 2\times10^{14}$ n_{eq}/cm^2
1. ***Minimum on Vdep vs fluence***
2. ***Slope of annealing curves***

Double junction model

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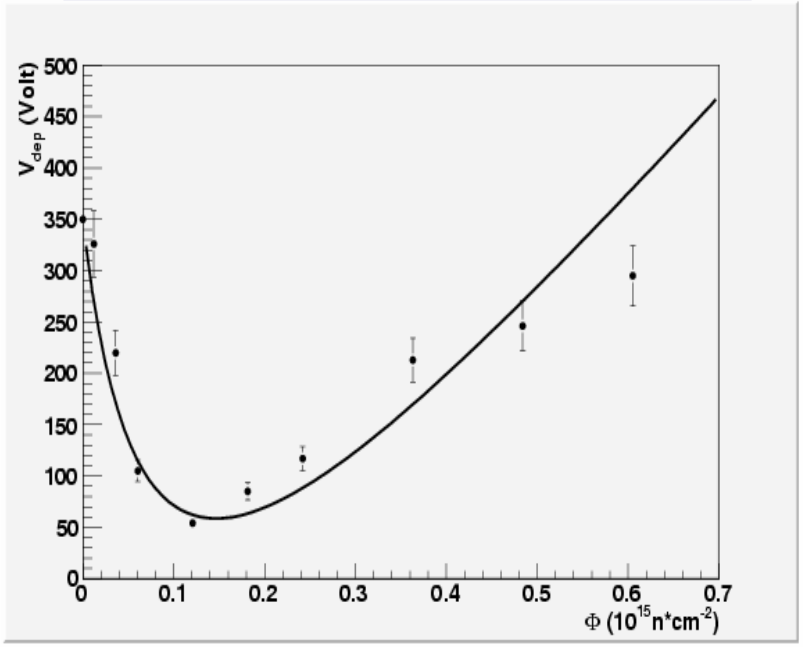
PROTON IRRADIATION



$$N_1 = b_1(\phi_i - \phi)$$
$$N_2 = b_2(\phi - \phi_0)$$

b_i = introduction rate of defect in the junctions

Φ_i =inversion fluence

Φ_0 =double junction formation fluence

$$V_{dep} \propto (N_1 + N_2) - \frac{3N_1N_2}{(N_1 + N_2)}$$

Annealing @60 ^{0}C
(MCz n Type)

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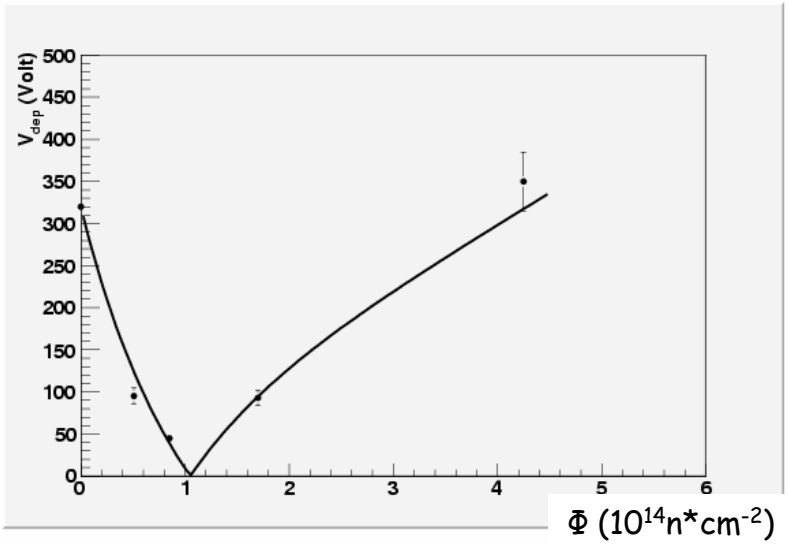

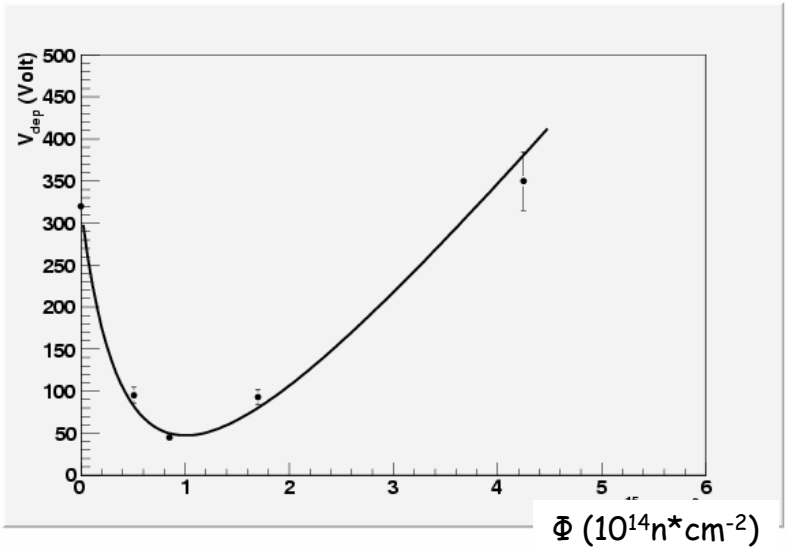

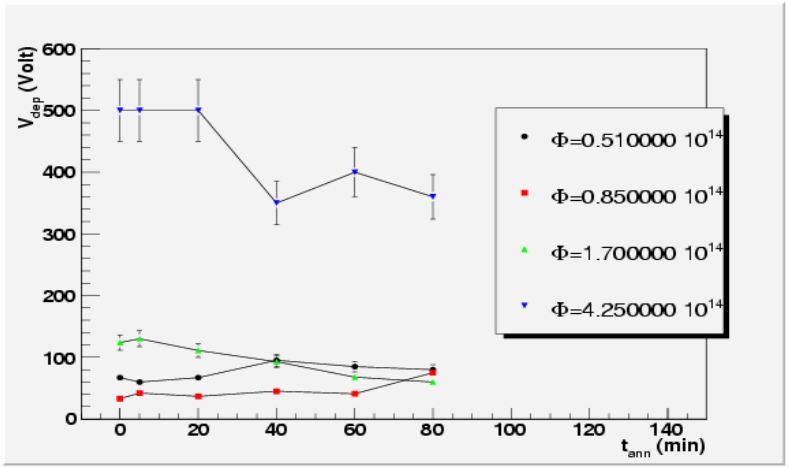

NEUTRON IRRADIATION

T=60^{0}C

Annealing @ 80°C

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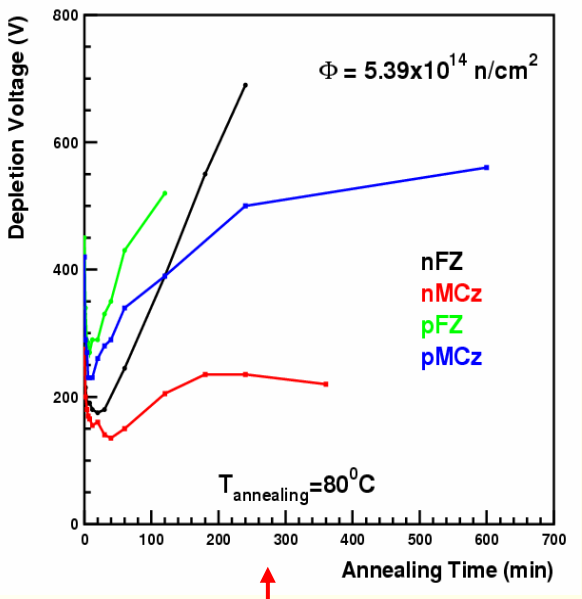
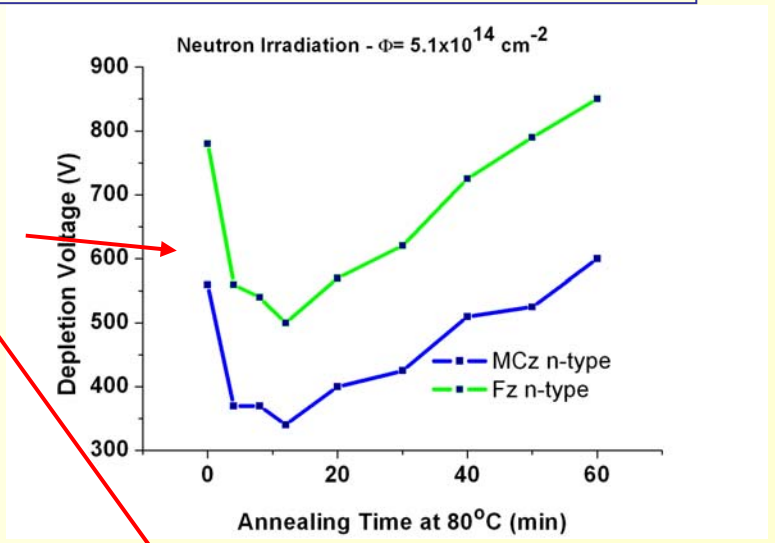
PROTON IRRADIATION



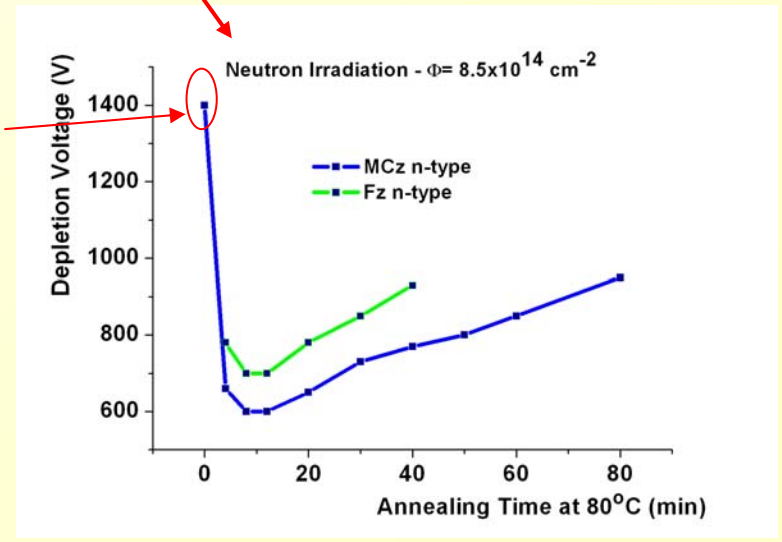
The difference in the annealing for protons started at longer ann. Times, where MCz improved.

NEUTRON IRRADIATION

Up to 60 min at 80 C for neutron irr. Fz and MCz show the same behavior.



extrapolated



Charge Collection Efficiency

Si detectors MCz p-type

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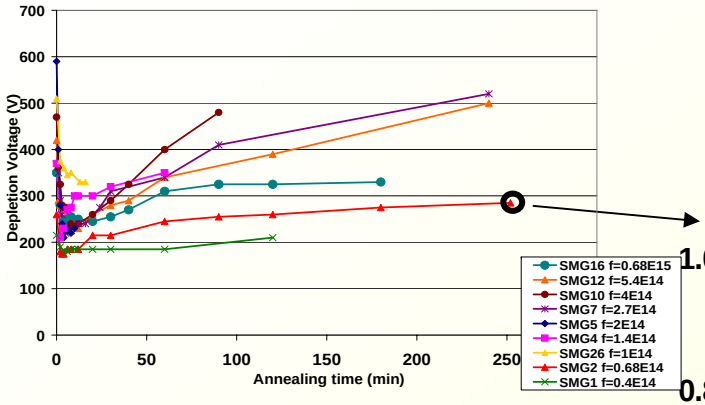
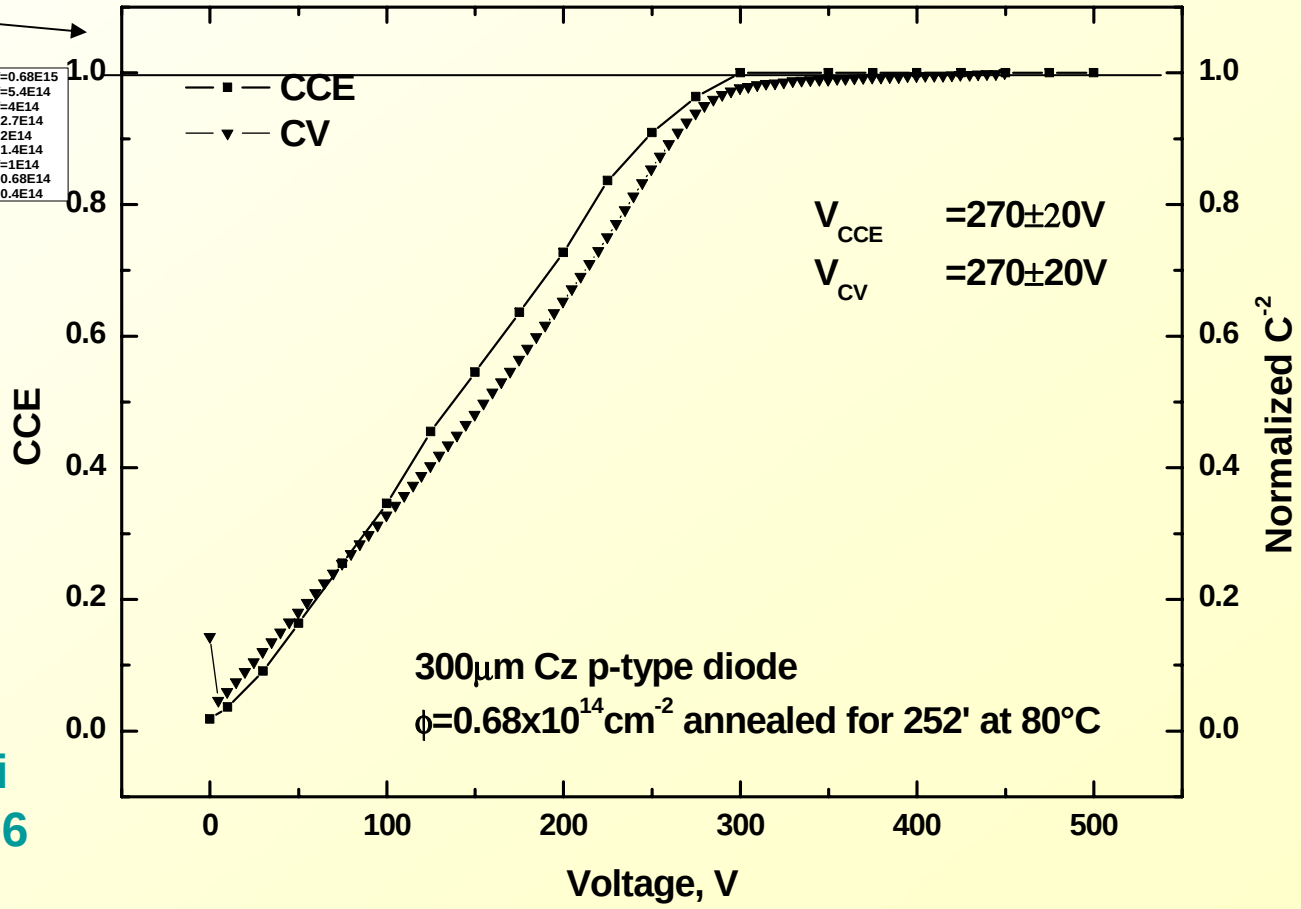
PROTON IRRADIATION

$\Phi = 6.8\ 10^{13}\ cm^{-2}$



CCE 100%
At full depletion

$V_{CCE} \sim V_{CV}$



Carlo Tosi, Mara Bruzzi
II Workshop Trento 2006

Charge Collection Efficiency

of Si detectors MCz p-type

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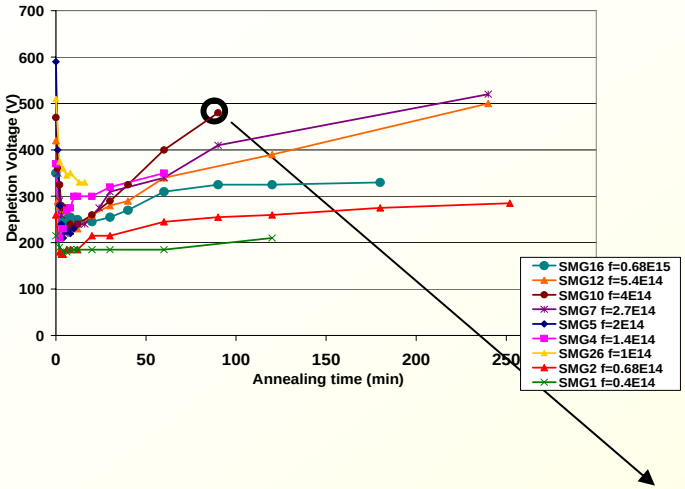


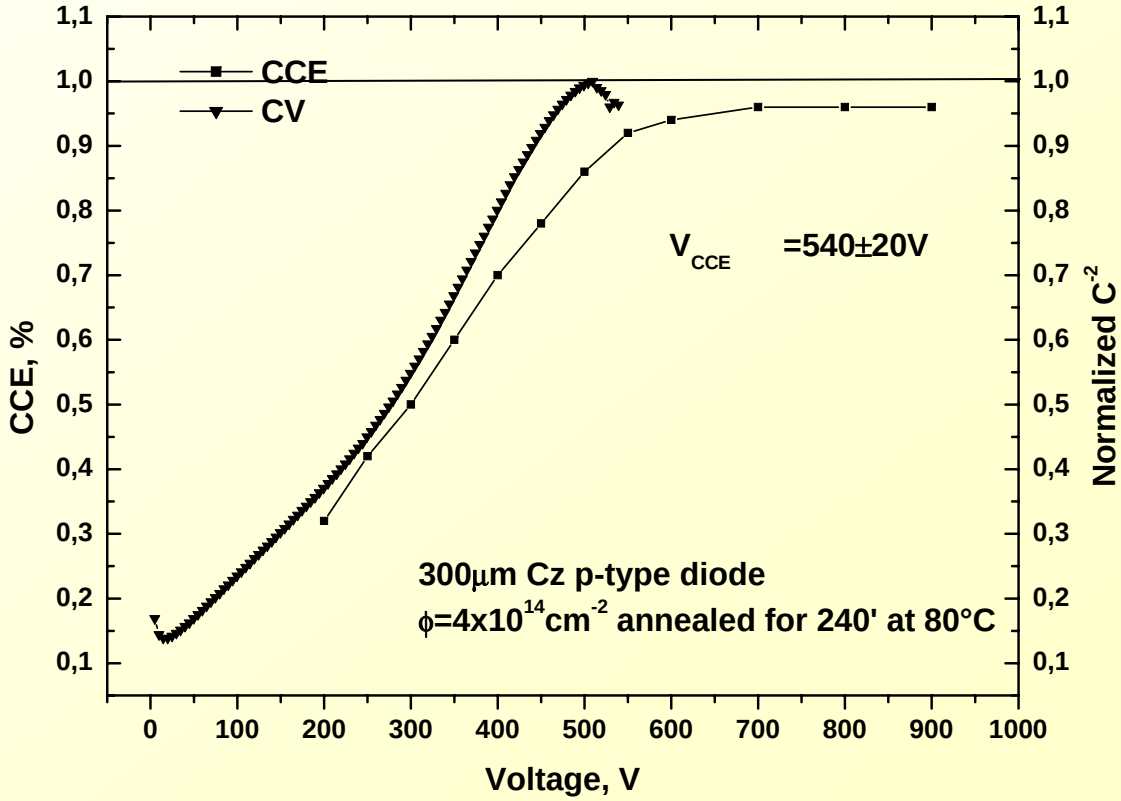
V_{CCE} = 540 V
V_{CV} = 500V

but

CCE ~ 86% 500V
CCE ~ 96% 700V

PROTON IRRADIATION

$\Phi = 2.7\ 10^{14}\ cm^{-2}$



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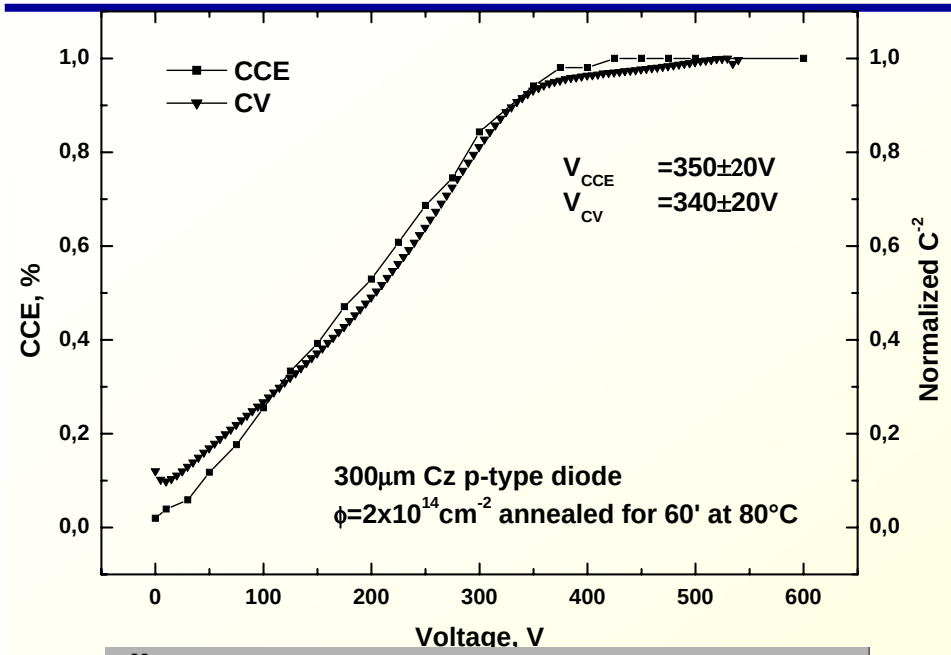
CCE of single pad MCz Si n-on-p

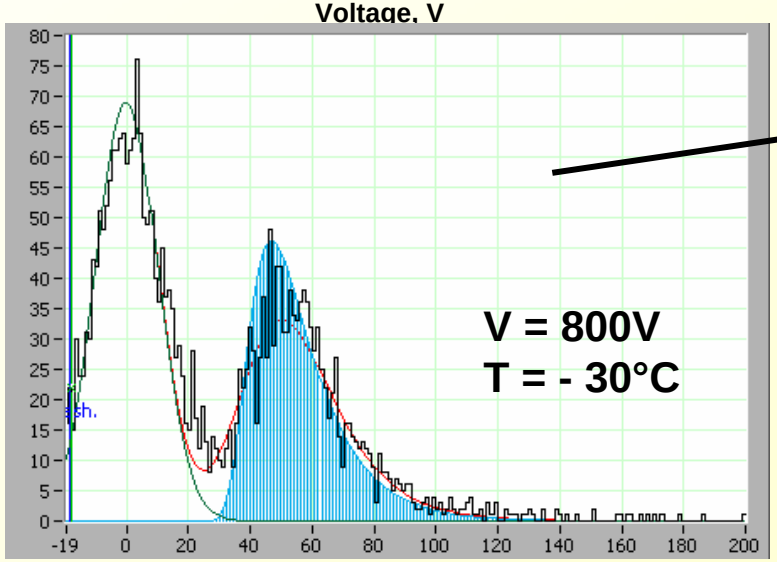
PROTON IRRADIATION



$\Phi = 1.36\ 10^{14}\ cm^{-2}$

CCE 100%

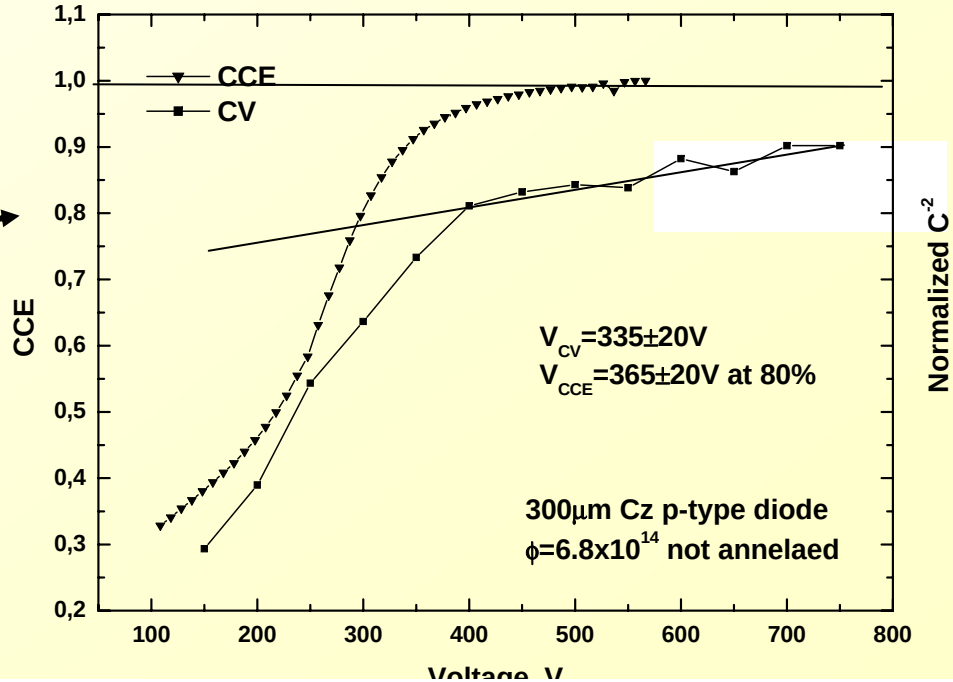
at full depletion $V_{CCE} \sim V_{CV} = 340V$



$\Phi = 6.8\ 10^{14}\ cm^{-2}$

CCE 75 % @ $V_{fd} = 350V$

CCE 90% @ 700V



Epitaxial 150µm

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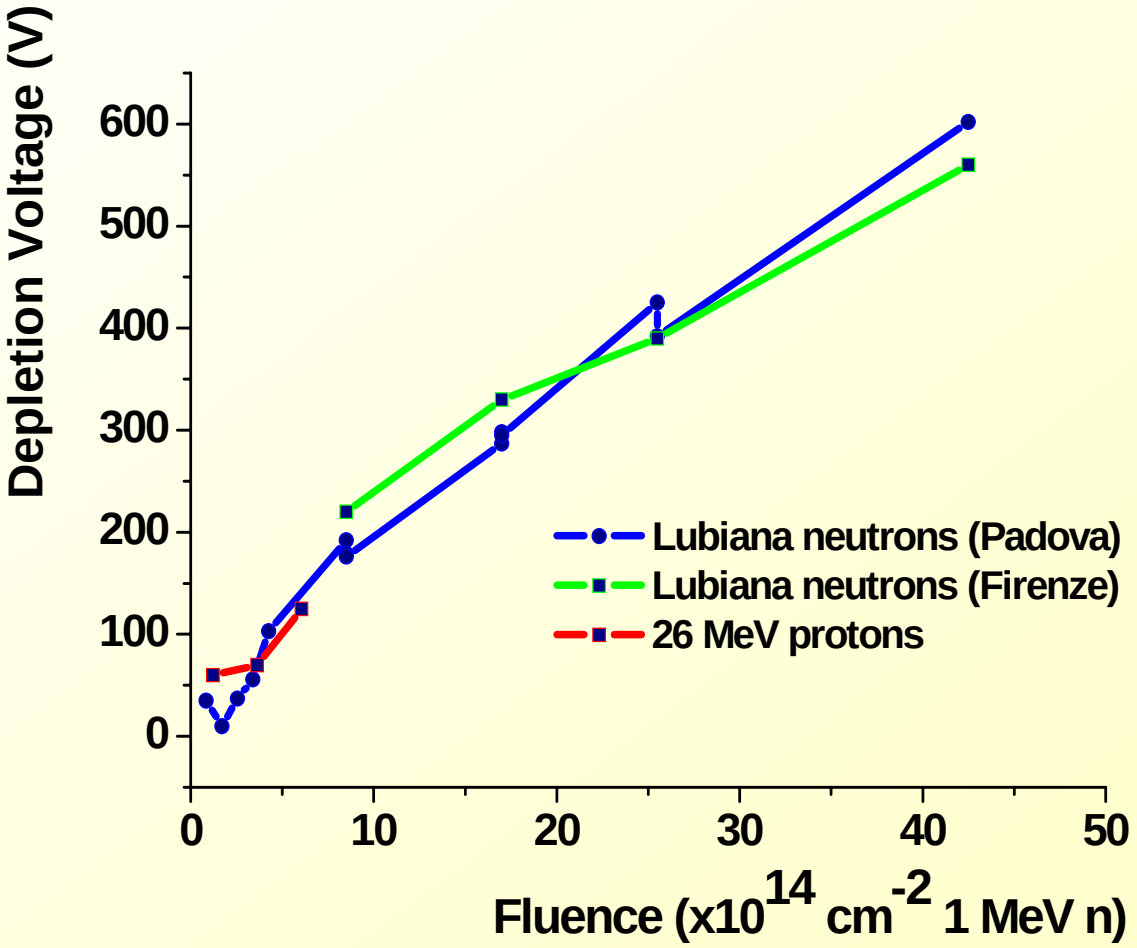
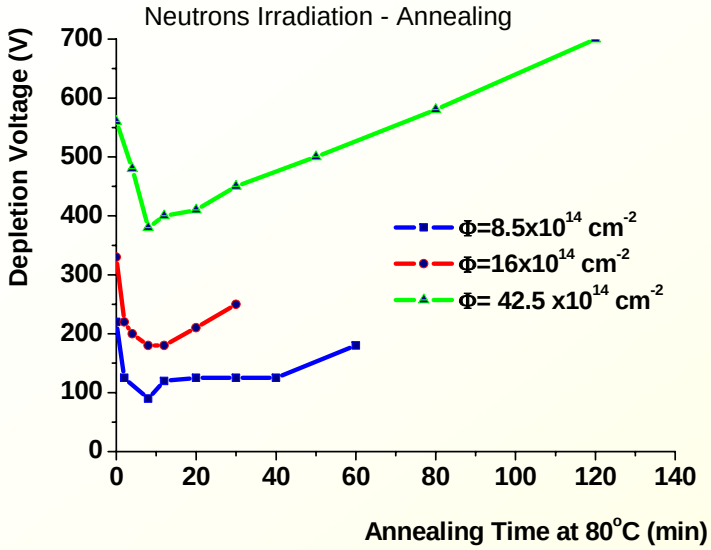
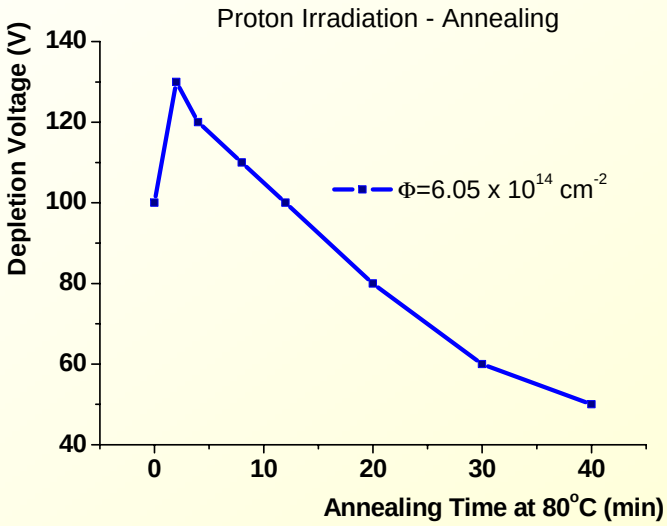
- Strong increase of the depletion voltage vs fluence
- Vdepl at the minimum is around 10 V: inversion or double junction effect?



Epitaxial Annealing



Neutrons: "inverted-like" behaviour



Protons: "not inverted-like" behaviour

MOS

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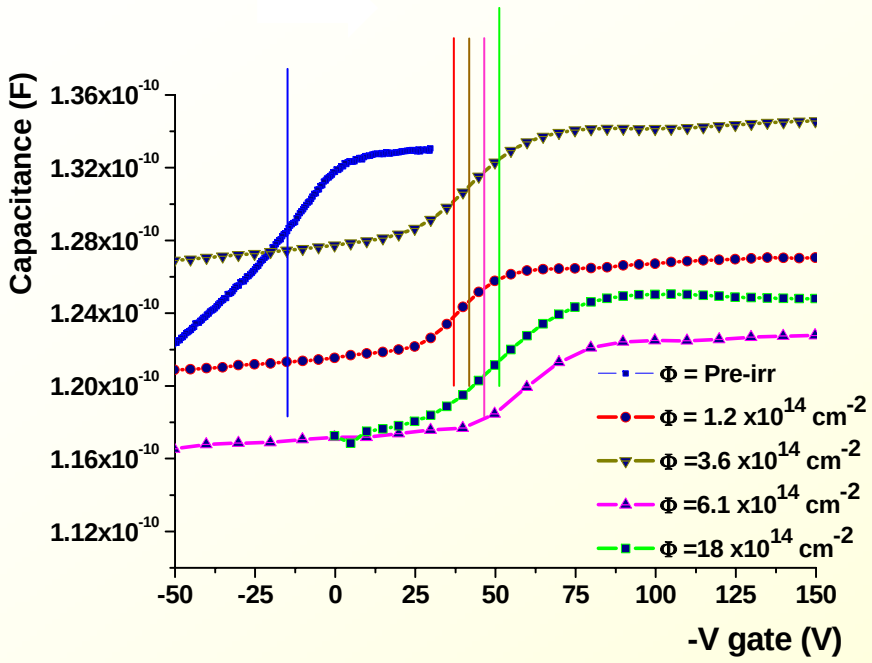
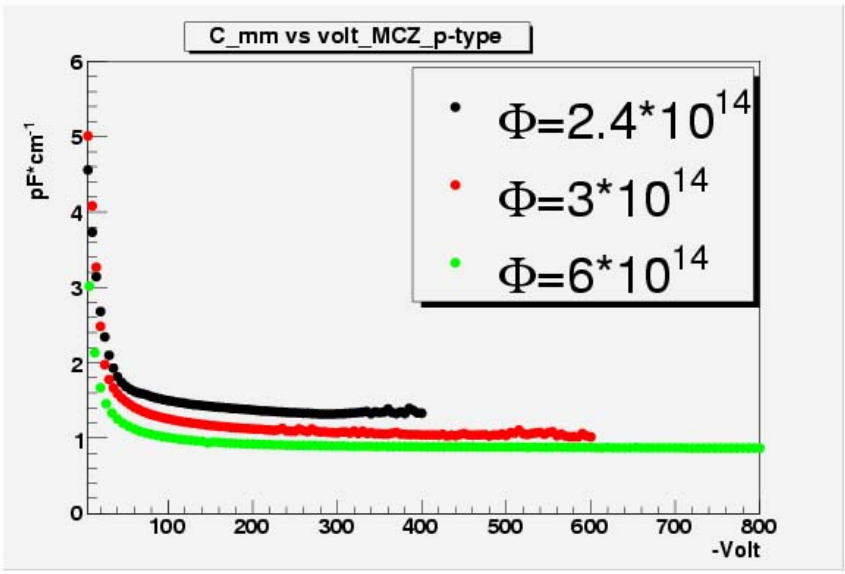
V_{fb}



C_{int}

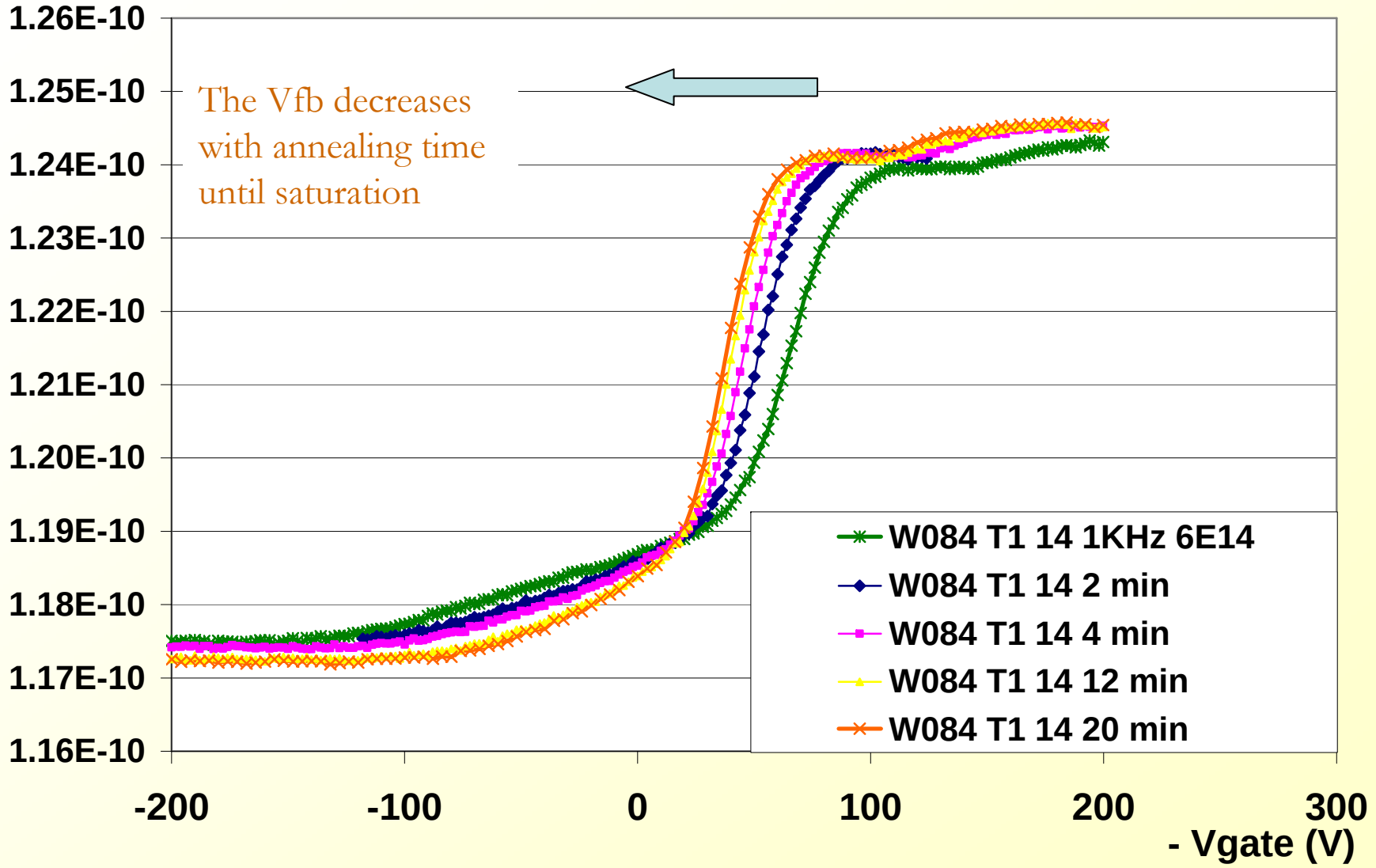


Measured before annealing @ 0°C

See Piemonte's talk 7th RD50 - Workshop

Annealing studies at 80 °C on the MOS structure

Fz p-type with high p-spray f= 1K Hz



Conclusions

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1. From TCT measurements the MCz n-type diodes irradiated with protons are not type inverted up to fluence $1*10^{15}$ ncm^{-2} and DJ observed above $3*10^{14}ncm^{-2}$
2. Experimental measurements are in better agreement with a Double Junction model than standard one.
3. Work in progress to improve this model in agreement with the experimental measurements and investigate the annealing behavior through this model.
4. No difference with the irradiation (proton-neutron) in terms of DJ model.

5. CV and CCE profiles and full depletion voltage values in good agremeent up to $\Phi = 1.36$ 10^{14} cm^{-2}.
6. CCE 96% and 90% at the highest fluences tested ($2.7 - 6.8*10^{14}cm^{-2}$) and at different annealing steps (0 and 252min at 80°C).

7. Epitaxial-150µm n-type diodes behaves like "inverted" @ $8*10^{14}cm^{-2}$

8. The V_{fb} increases continuously with fluence
9. Interstrip Capacitance variation observed on Microstrip sensors up to $6*10^{14}cm^{-2}$.