EP-DT
Detector Technologies

NIEL hardness factor determination for the new proton irradiation facility at CERN

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28TH RD50 WORKSHOP - JUNE 2016

Outline

1. <u>NIEL hardness factor determination</u>
    - New CERN facility
    - Experimental determination of α, κ
    - Conclusions and future work
2. Activation energy
    - Review of data taken within CERN's SSD team
    - Conclusions and future work

IRRAD proton facility @ CERN

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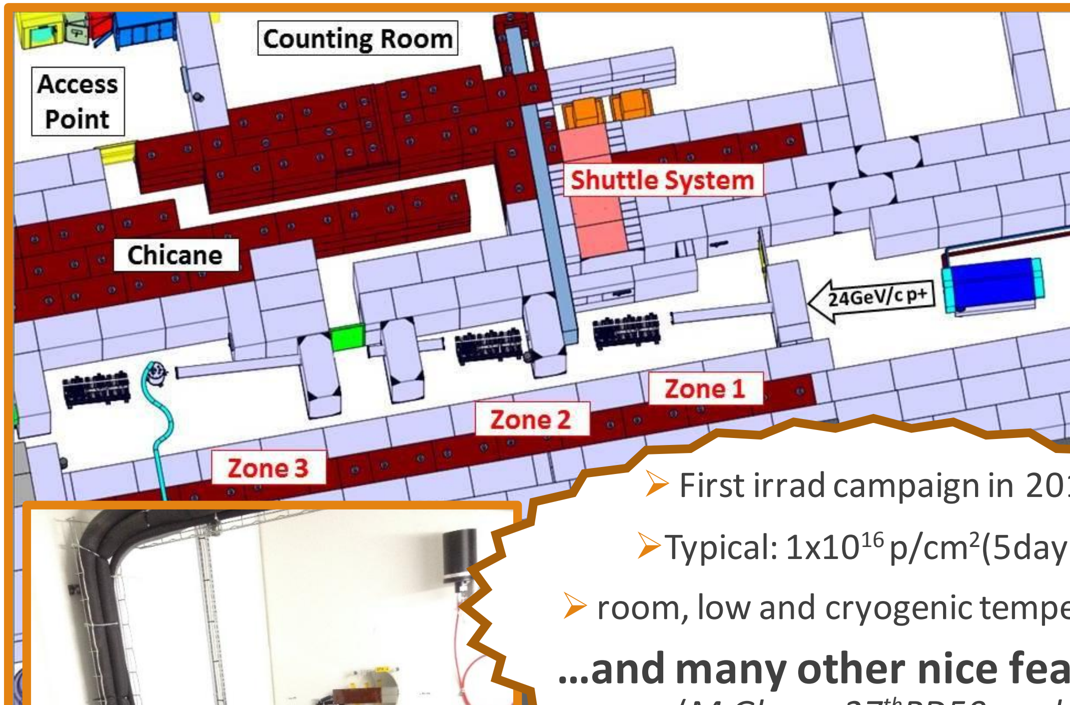


- First irrad campaign in 2015
- Typical: 1×10^{16} p/cm^2(5days)$^{-1}$
- room, low and cryogenic temperatures

...and many other nice features!

(*M.Glaser, 27thRD50 workshop*)

URL: www.cern.ch/ps-irrad

e-mail: irradiation.facilities@cern.ch

Experimental determination of α, κ

- Current related damage rate (α):

$$\Delta I = \alpha\, \varphi\, V \qquad \text{(NIEL hypothesis)}$$

- Hardness factor (κ)

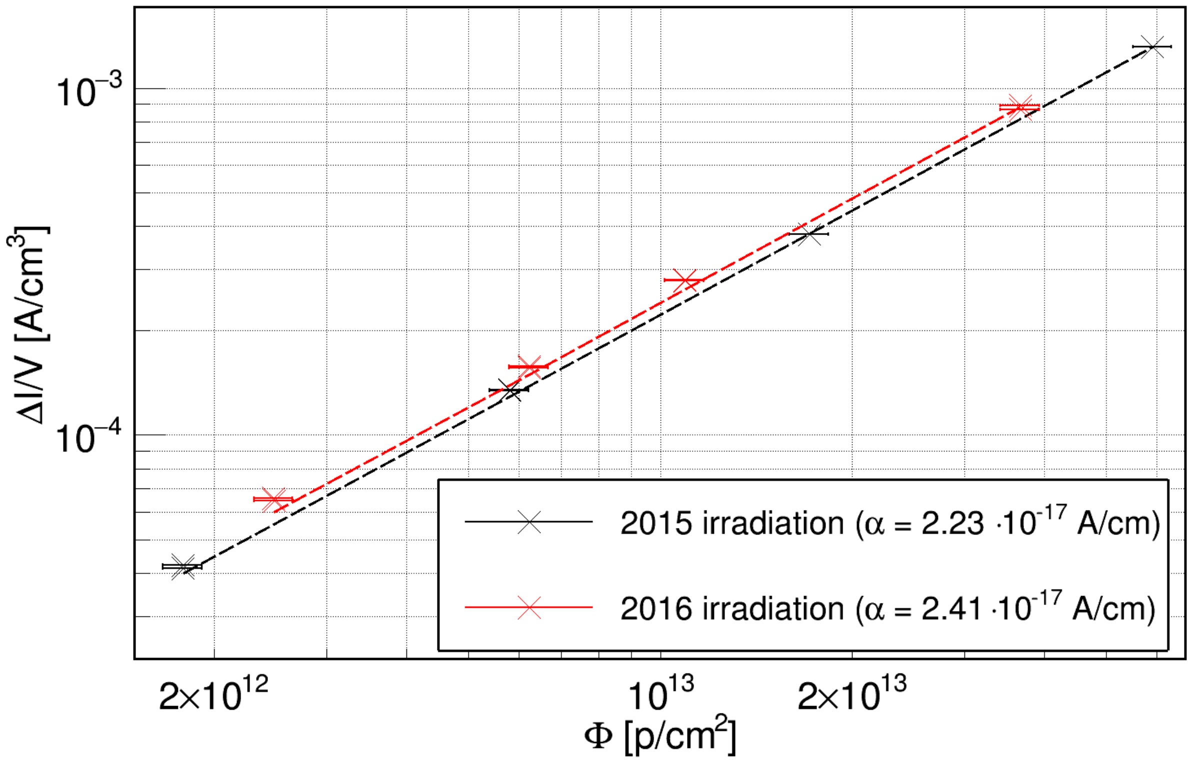
$$\varphi_{eq} = \kappa\, \varphi$$

- Experimental method:

$$\kappa = \alpha / \alpha_{1MeV}$$

- α calculated from 2 sets of irradiated diodes:
  - Irradiations in 2015, 2016 campaigns
  - FZ n-type pad diodes from STM
  - 5x5mm area, 295µm thickness, 2KΩ resistivity
  - 8 diodes per set (2 x 4 different fluences)

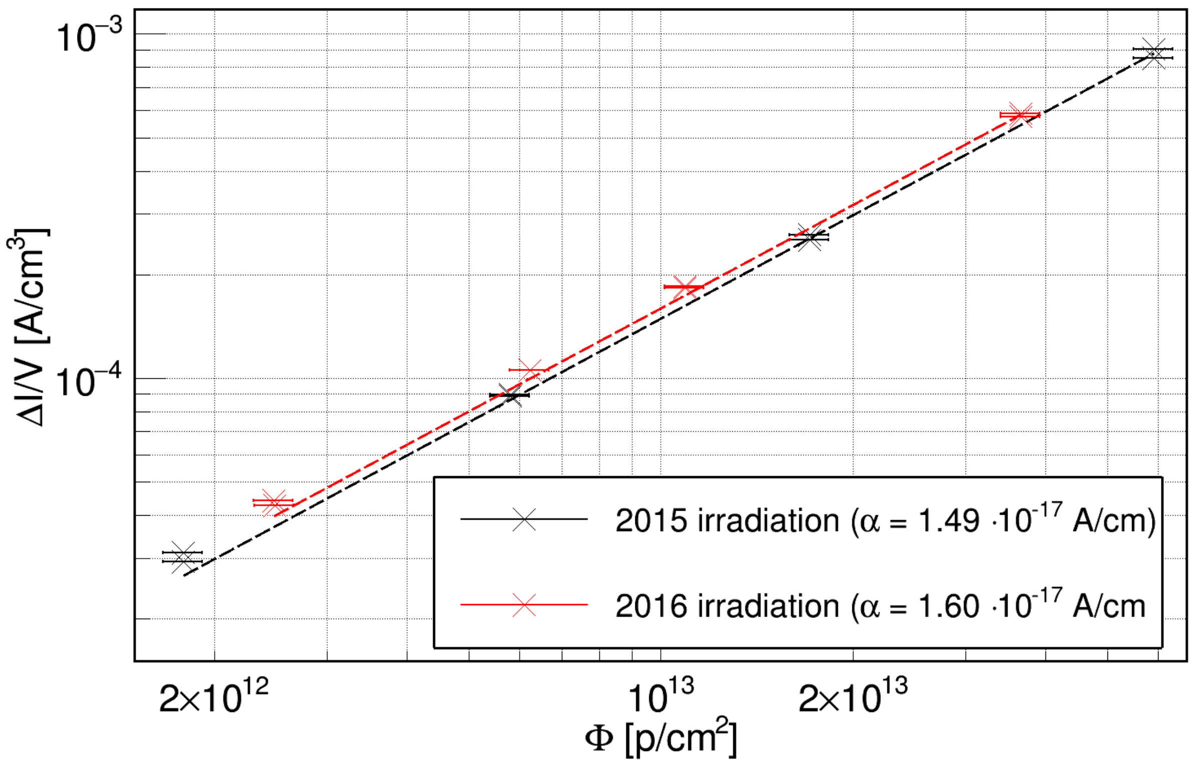
Results after annealing: 80 min at 60ºC



Irradiation	α_{IRRAD} [1e-17 A/cm]	k_{IRRAD}(*)
2015	2.23	0.56
2016	2.41	0.60

(*) α_{1MeV} = 4.01e-17 A/cm, from M.Moll thesis

Results after annealing: 1440 min at 60ºC



Irradiation	α_{IRRAD} [1e-17 A/cm]
2015	1.49
2016	1.60

Conclusions and future work

- Experimental determination of hardness factor for the new proton irradiation facility is ongoing
- First results show a discrepancy between the two irradiations
  - Not related to annealing (both sets annealed together in the 2^{nd} step)
- More data is needed
  - New set of diodes irradiated as we speak
  - Background removal using reference diode (out of beam)

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2. <u>Activation energy</u>
    - Review of measurements within CERN’s SSD team
    - Conclusions and future work

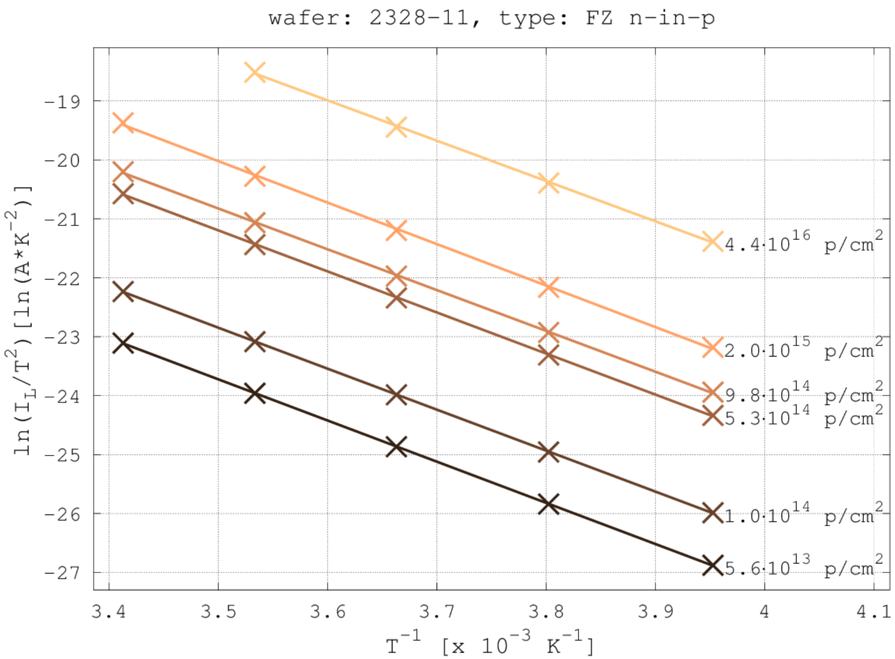
Review of measurements within CERNS's SSD team

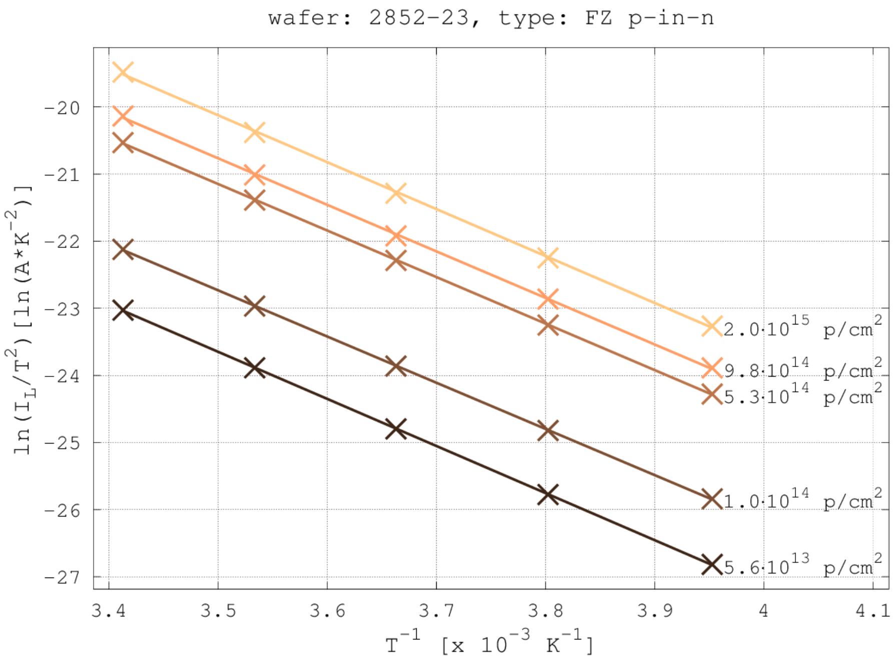
- I-V data from different sensor types irradiated at different fluences (*H.Neugebauer, 22nd RD50 workshop*)
  - Types: FZ p-in-n, n-in-p, n-in-n; MCZ n-in-p
  - Fluences from $5.6 \times 10^{13}\ p/cm^2$ to $4.4 \times 10^{16}\ p/cm^2$
  - Sensors measured at several temperatures from -20°C to 20°
  - After beneficial annealing (80 min at 60°C)
- The data is used to fit the theoretical dependency of leakage current with temperature

$$I_L(T) \propto T^2 e^{-\frac{E_a}{2K_b T}} \quad \Rightarrow \quad \ln\left(\frac{I_L(T)}{T^2}\right) = K - \frac{E_a}{2K_b}\frac{1}{T}$$

(Linear fit: a + bx)

Results: $FZ_{n\text{-}in\text{-}p}$, $FZ_{p\text{-}in\text{-}n}$

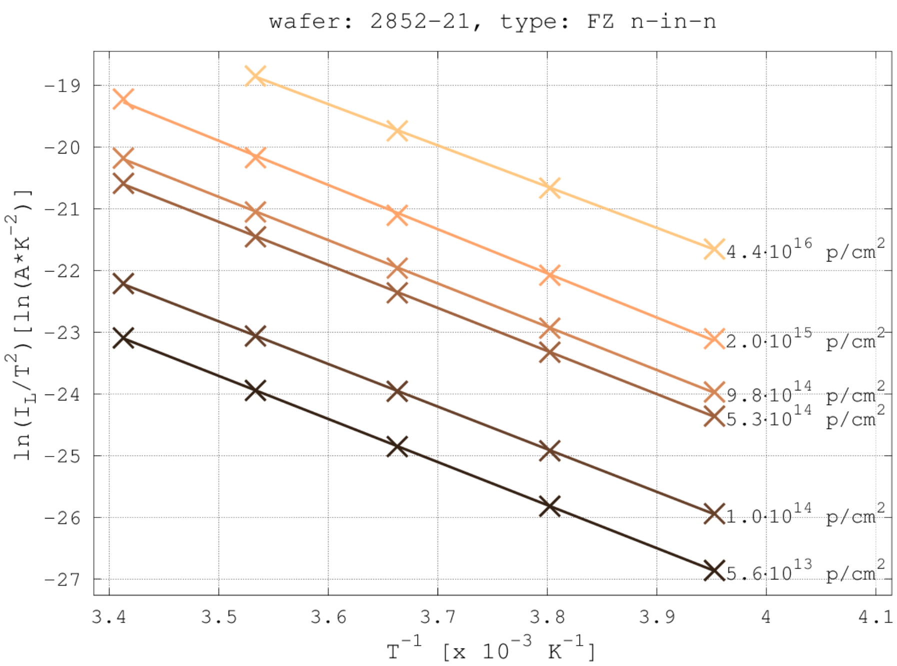


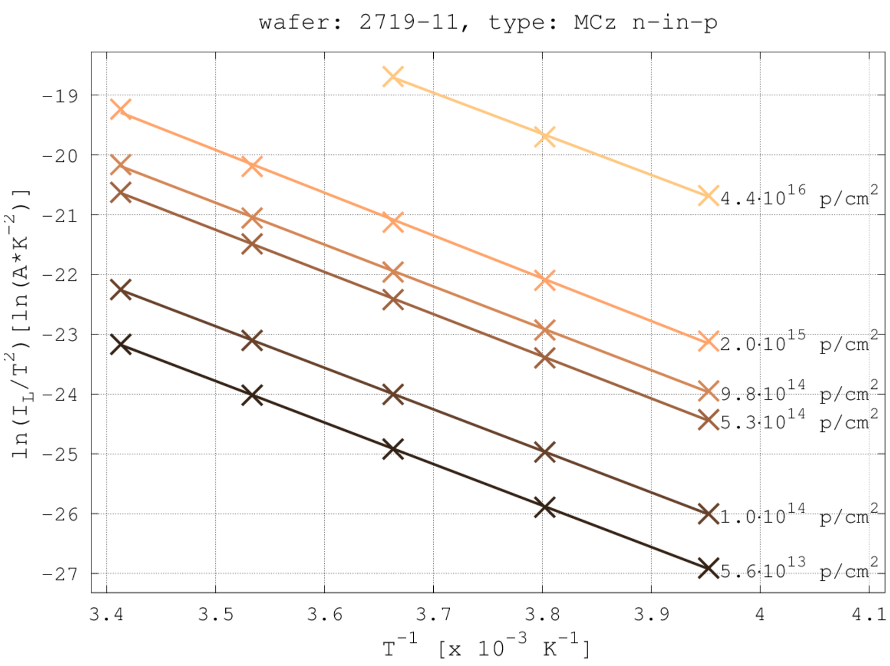


Fluence [p/cm²]	Ea [eV]
5.6E+13	1.205
1.0E+14	1.199
5.3E+14	1.201
9.8E+14	1.194
2.0E+15	1.214
4.4E+16	1.179
Mean value:	**1.20 ± 0.01**

Fluence [p/cm²]	Ea [eV]
5.6E+13	1.21
1.0E+14	1.187
5.3E+14	1.195
9.8E+14	1.196
2.0E+15	1.205
Mean value:	**1.20 ± 0.01**

Results: $FZ_{n\text{-}in\text{-}n}$, $MCZ_{n\text{-}in\text{-}p}$





Fluence [p/cm²]	Ea [eV]
5.6E+13	1.203
1.0E+14	1.191
5.3E+14	1.203
9.8E+14	1.209
2.0E+15	1.235
4.4E+16	1.152
Mean value:	**1.20 ± 0.03**

Fluence [p/cm²]	Ea [eV]
5.6E+13	1.197
1.0E+14	1.198
5.3E+14	1.216
9.8E+14	1.207
2.0E+15	1.233
4.4E+16	1.184
Mean value:	**1.21 ± 0.02**

Results: summary

$$E_a = 1.20 \pm 0.02 \text{ [eV]}$$

Wafer	Type		Fluence [p/cm^2]	Ea [eV]
2328-11	FZ	n-in-p	5.60E+13	1.205
2852-21	FZ	n-in-n	5.6E+13	1.203
2852-23	FZ	p-in-n	5.6E+13	1.21
2719-11	MCz	n-in-p	5.6E+13	1.197
2328-11	FZ	n-in-p	1.00E+14	1.199
2852-21	FZ	n-in-n	1.0E+14	1.191
2852-23	FZ	p-in-n	1.0E+14	1.187
2719-11	MCz	n-in-p	1.0E+14	1.198
2328-11	FZ	n-in-p	5.30E+14	1.201
2852-21	FZ	n-in-n	5.3E+14	1.203
2852-23	FZ	p-in-n	5.3E+14	1.195
2719-11	MCz	n-in-p	5.3E+14	1.216
2328-11	FZ	n-in-p	9.80E+14	1.194
2852-21	FZ	n-in-n	9.8E+14	1.209
2852-23	FZ	p-in-n	9.8E+14	1.196
2719-11	MCz	n-in-p	9.8E+14	1.207
2328-11	FZ	n-in-p	2.00E+15	1.214
2852-21	FZ	n-in-n	2.0E+15	1.235
2852-23	FZ	p-in-n	2.0E+15	1.205
2719-11	MCz	n-in-p	2.0E+15	1.233
2328-11	FZ	n-in-p	4.40E+16	1.179
2852-21	FZ	n-in-n	4.4E+16	1.152
2719-11	MCz	n-in-p	4.4E+16	1.184

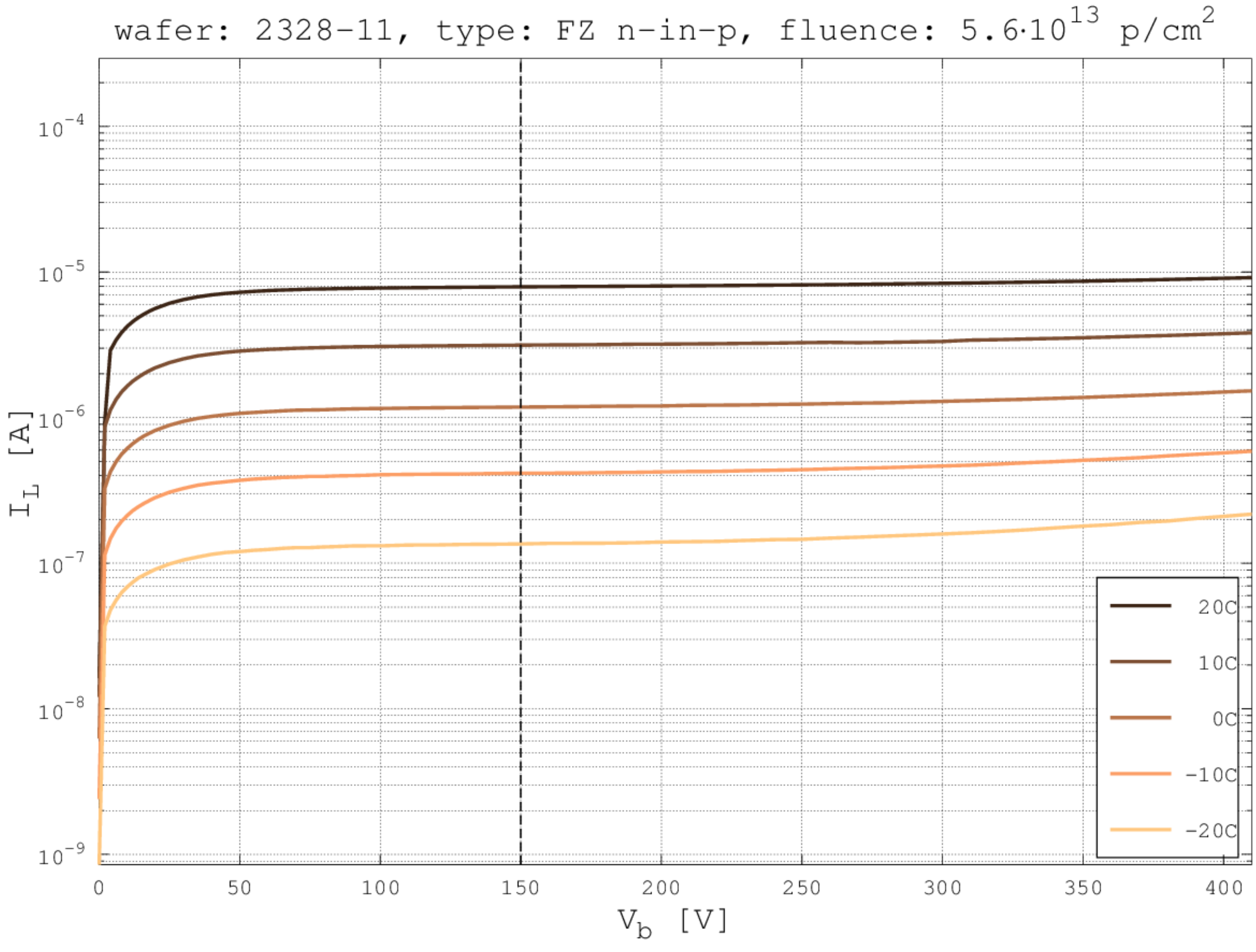
Conclusions and future work

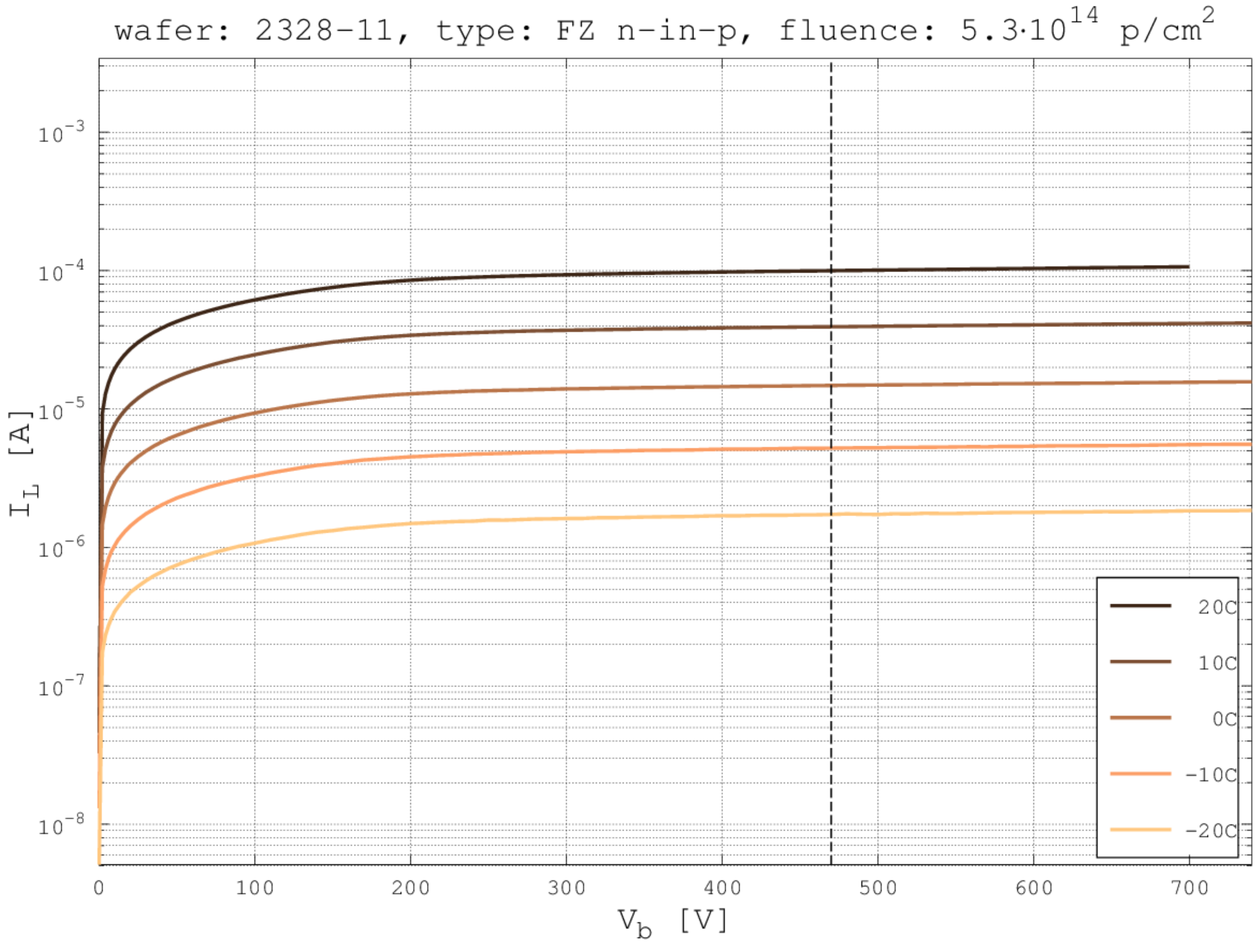
- Analysis based on a set of 23 diodes of different types, irradiated with fluences from $5.6x10^{13}$ p/cm^2 to $4.4x10^{16}$ p/cm^2 yields an activation energy of 1.20 eV in the [-20^{o}C, 20^{o}C] temperature range

- These results should be completed with additional measurements at lower temperatures to study in detail the variation of the activation energy in a wider temperature range.

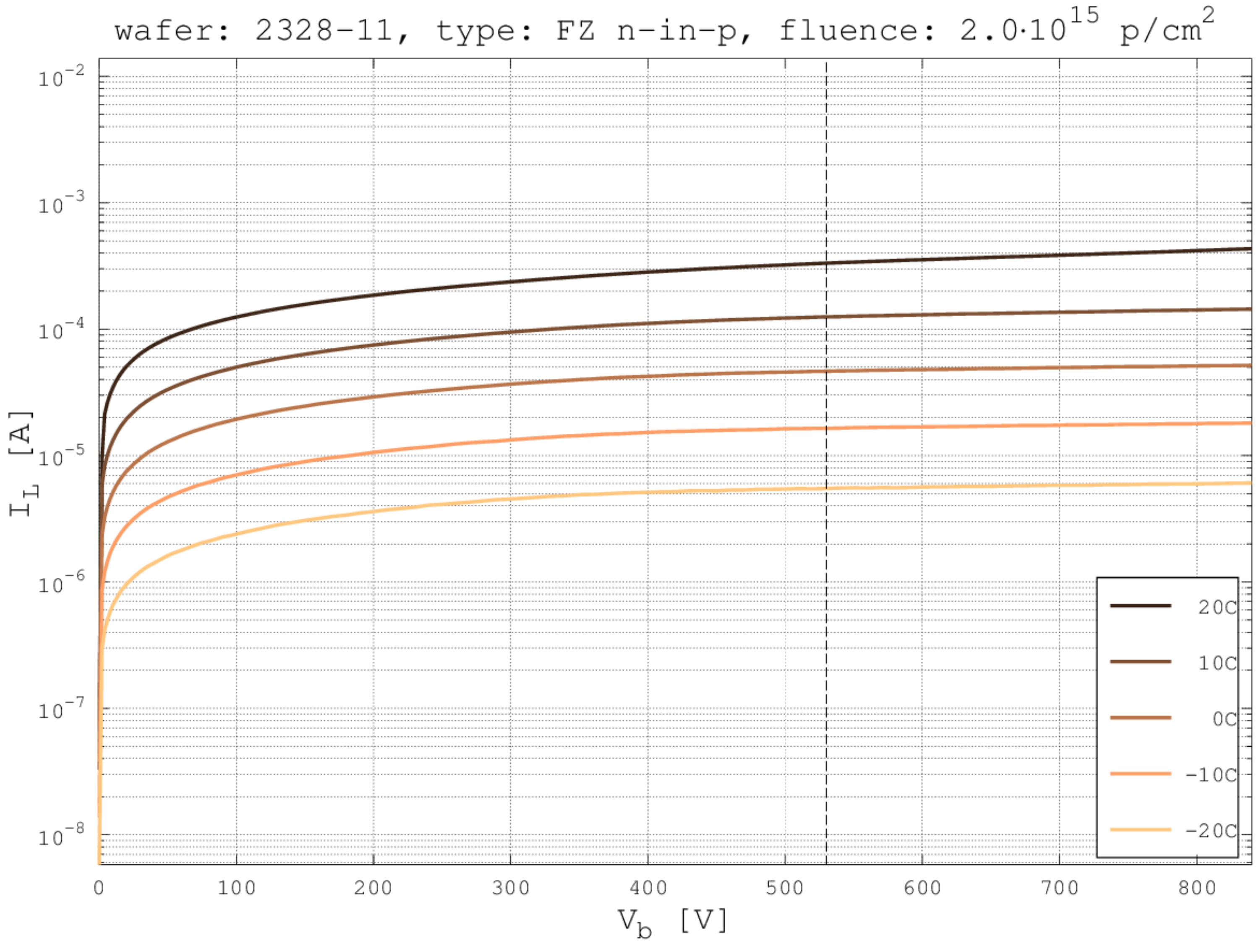
Thank you for your attention!

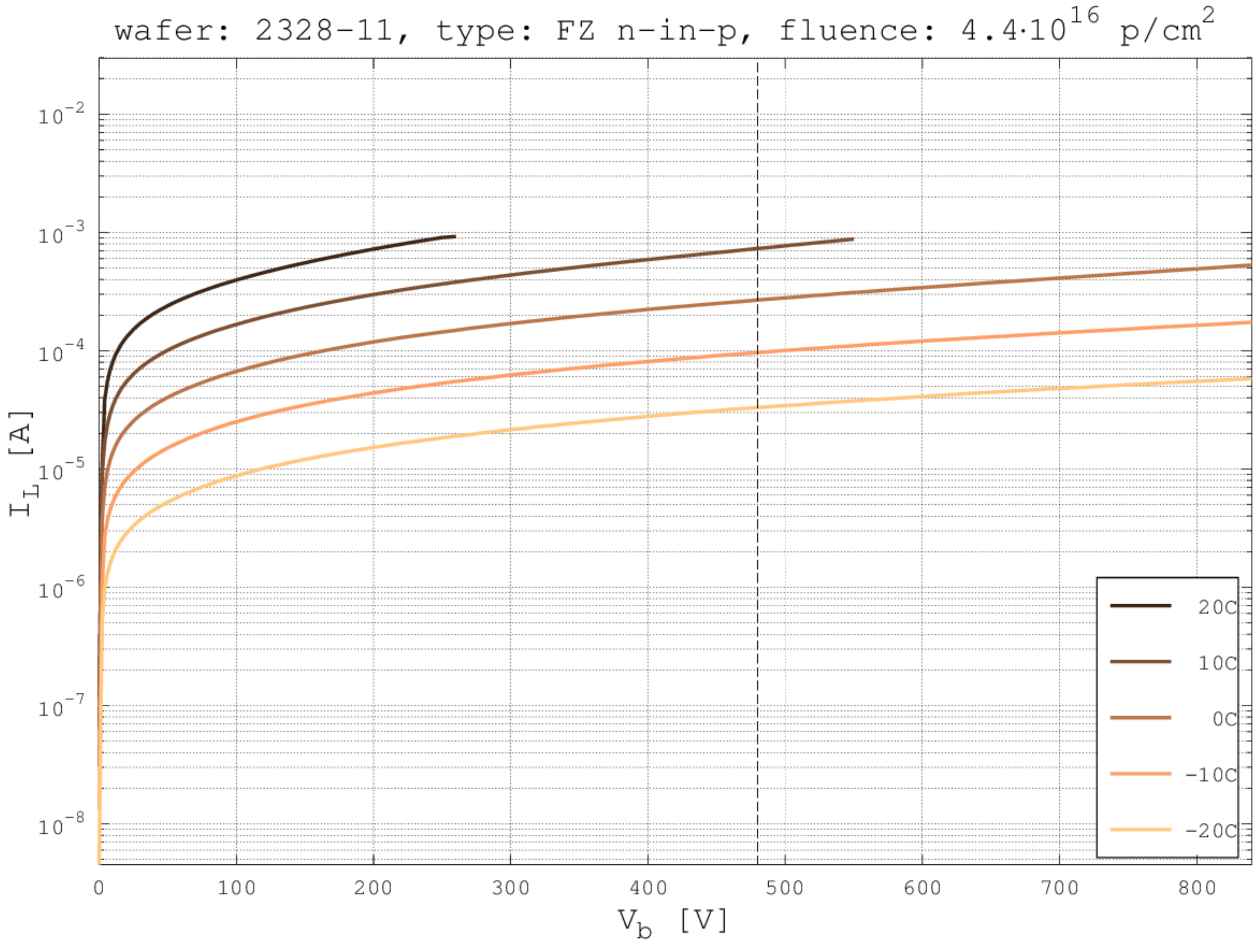
Backup slides

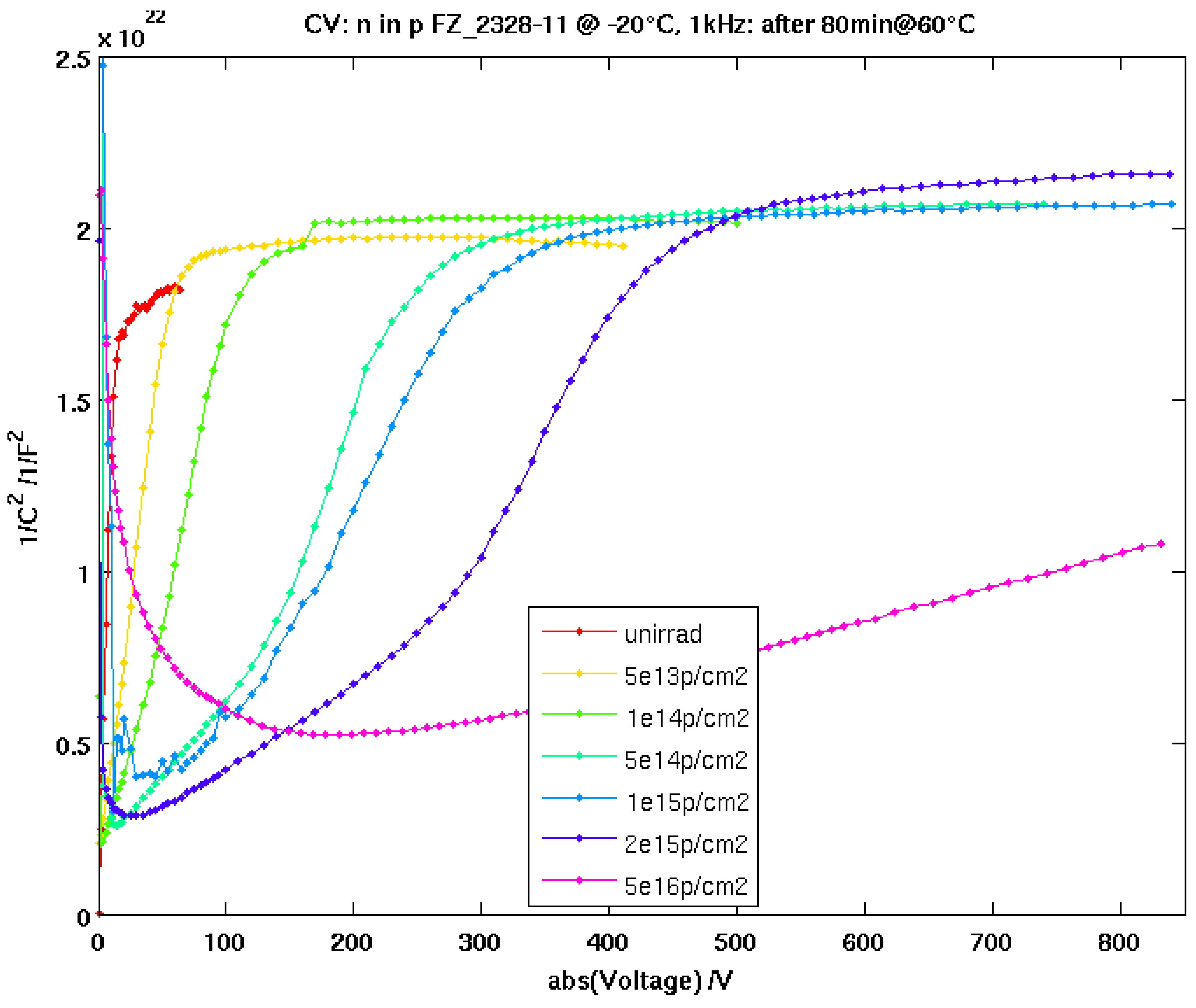

wafer: 2328-11, type: FZ n-in-p, fluence: 5.6·10^13 p/cm^2
I_L [A]
V_b [V]
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
0
50
100
150
200
250
300
350
400
20C
10C
0C
-10C
-20C



wafer: 2328-11, type: FZ n-in-p, fluence: 5.3·10^14 p/cm^2
I_L [A]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0
100
200
300
400
500
600
700
V_b [V]
20C
10C
0C
-10C
-20C


wafer: 2328-11, type: FZ n-in-p, fluence: 2.0·10^15 p/cm^2
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
I_L [A]
0
100
200
300
400
500
600
700
800
V_b [V]
20C
10C
0C
-10C
-20C


wafer: 2328-11, type: FZ n-in-p, fluence: 4.4·10^16 p/cm^2
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
I_L [A]
0
100
200
300
400
500
600
700
800
V_b [V]
20C
10C
0C
-10C
-20C


CV: n in p FZ_2328-11 @ -20°C, 1kHz: after 80min@60°C
x 10^22
2.5
2
1.5
1
0.5
0
1/C^2 /1/F^2
0
100
200
300
400
500
600
700
800
abs(Voltage) /V
unirrad
5e13p/cm2
1e14p/cm2
5e14p/cm2
1e15p/cm2
2e15p/cm2
5e16p/cm2