Overview of results on charge collection in ATLAS strip detectors

by

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Outline

1. Approaches
2. INTAS project
3. Physics of Curren Injection Detectors (CID)
   - Electric field in sensitive region
   - I-V characteristics
   - Operational parameters
4. Experimental proof
   - structures of CIDs
   - preirradiation test
   - Irradiation
   - CIDs evaluation
5. Conclusions

Two ways of Si-detectors radiation hardness improvement

Material engineering

Si dopped by:

- Oxygen
  - Oxy-diffusion
  - Cz-silicon
- Defects
  - epy-silicon
  - pre-irradiated

Problems:

- „Technological" factor
- No improvement for n^0

Detector engineering

→ Regular
→ 3D

Regular ⇓

- Increas of $V_{operational}$
- Temperature controled effects:

INTAS:
- Lazarus
- Electric field manipulation
- Space charge limited current in deep level rich Silicon

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electric field manipulation?

proach non sensitive for material
ties

simple physics

stable operational parameters

nd for any type of particles

d of INTAS project

ion by current injection in heavy
detectors

PTI NIM A360 (1995) 458

n of I-V characteristics of heavy
etectors after space charge sign inversion

PTI NIM A383 (1996) 528

ration at forward bias

ster, NIM A 395 (1997) 81, NIM A 399 (1997) 35, CERN RD39 NIM A 440 (2000) 5

ld manipulation by current injection

TI, INFN IEEE Trans NS V.4, N3 (1999) 221

TI IEEE NSS meeting, proceedings (2000)

solid state physics

Electric field manipulation

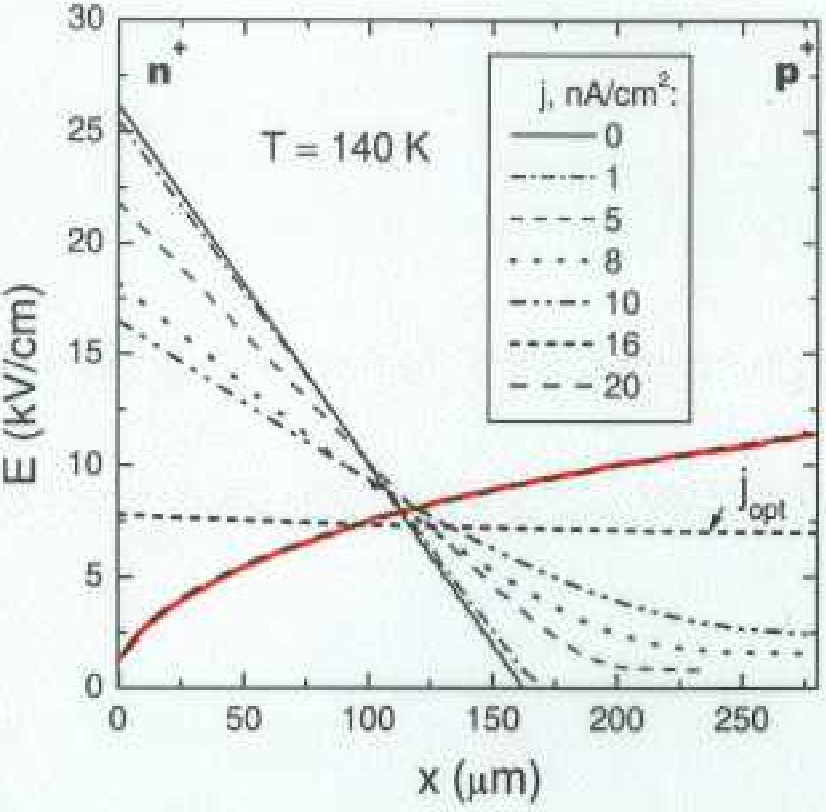
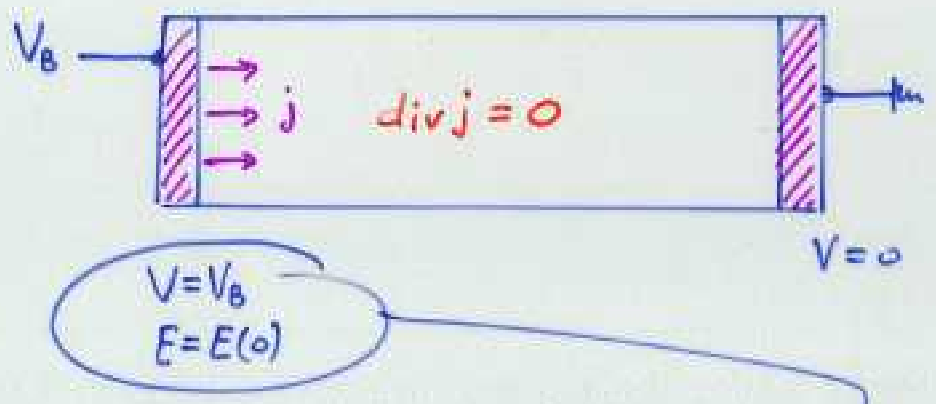


Fig. 5.1 Dependence of the electric field distribution on the hole injection current density in a Si detector irradiated by neutrons.
$\Phi_n = 1.4 \cdot 10^{14}\ cm^{-2}$; $V = 210$ V.

IEEE-NSS meeting, 2000

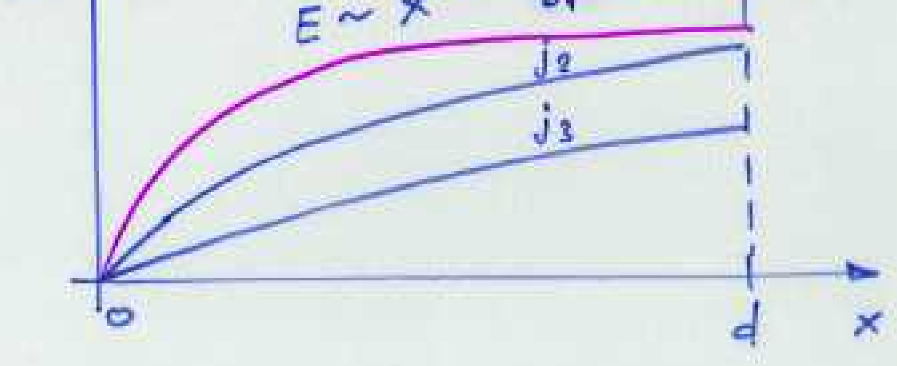
Electric field distribution in CID

(DL free material)



$$\begin{cases} j = e\mu n E(x) \\ \frac{\varepsilon}{e}\frac{dE}{dx} = n \end{cases} + \text{B.C.}$$

$$E(x) = \sqrt{\frac{2j}{\varepsilon\mu}}\, x^{1/2} \quad \text{at } E(0) = 0$$



$$V = f(j)$$

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Electric field distribution in CID

(DL rich material)

$$\begin{cases} j = e n \mu E \\ \dfrac{\varepsilon}{e} \dfrac{dE}{dx} = n_t \end{cases}$$

B.C.: $E(0) = 0$

$$\frac{n}{n_t} = \Theta << 1$$

$$n_t \propto N_{DL}$$

$$E(x) = \sqrt{2j \ldots}\; x^{1/2} \ldots \sqrt{N_{DL} \ldots}\; x^{1/2}$$

I-V characteristics of CID

Space charge Limited current

- DL free material

$$E(x) = \sqrt{\frac{2j}{\Theta \varepsilon \mu}}\, x^{1/2}$$

$$\Downarrow$$

$$j \sim \frac{\varepsilon \mu V^2}{d^3}$$

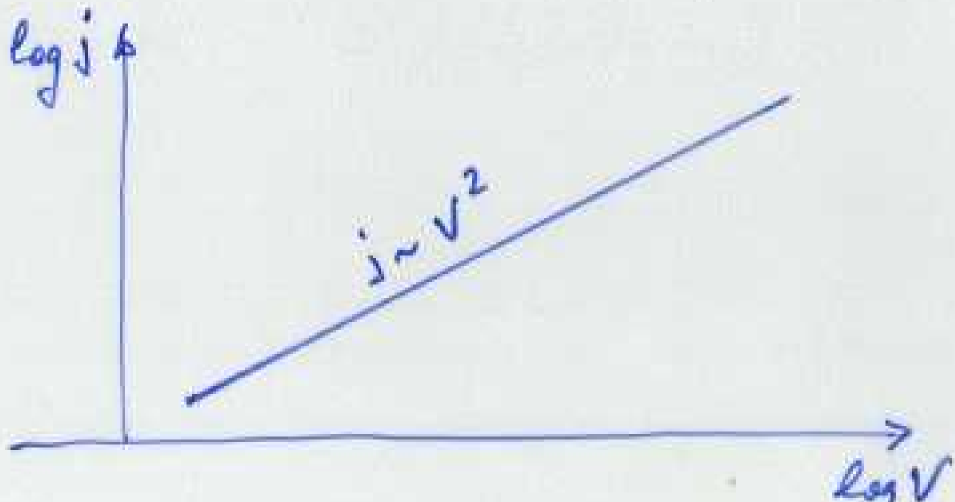
- DL rich material

$$E(x) = \sqrt{\frac{2j}{\Theta \varepsilon \mu}}\, x^{1/2}$$

$$j \sim \frac{\Theta \varepsilon \mu V^2}{d^3}$$

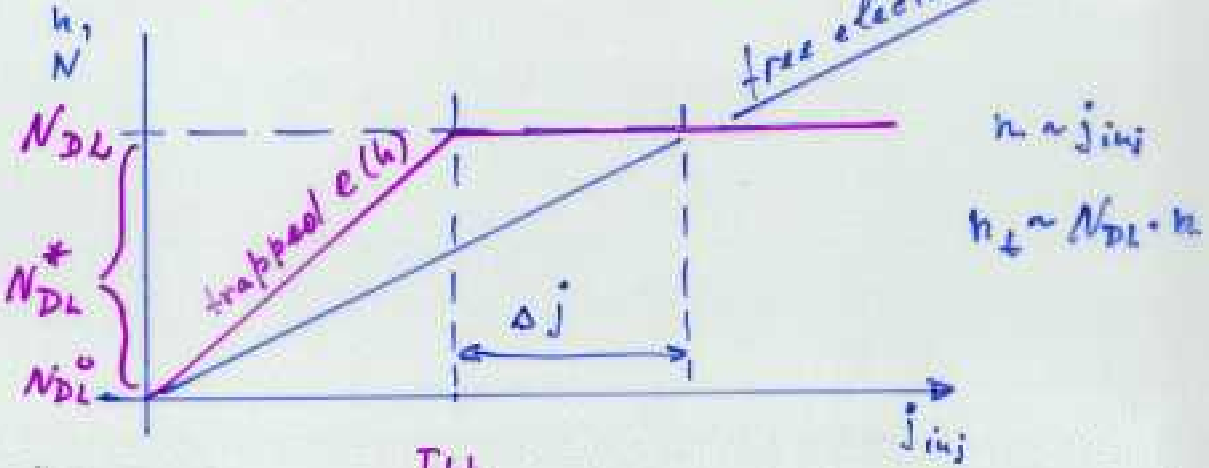
$\Theta = \frac{n}{n_t} \ll 1$

$j_{free\ car} \gg j_{DL}$!



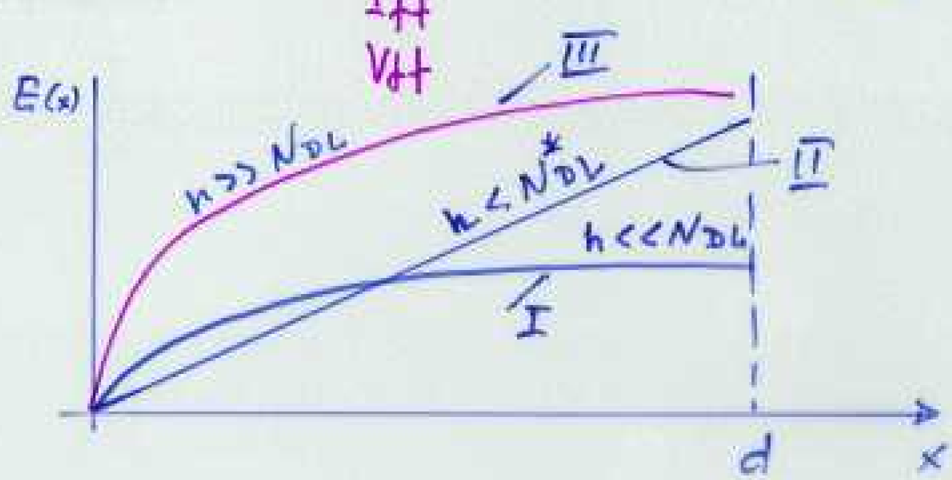
I-V characteristics of CID

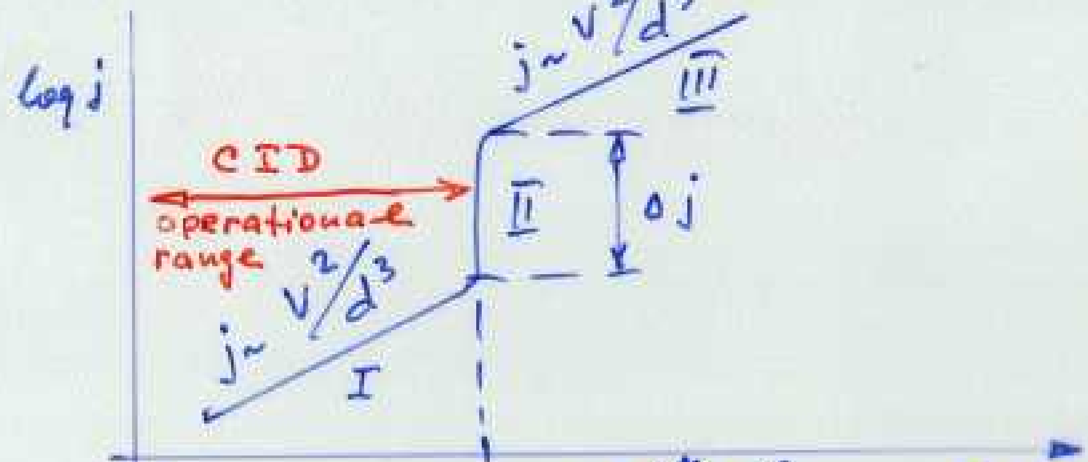
(DL rich material)
(wide current range)



$n \sim j_{inj}$

$n_t \sim N_{DL} \cdot n$





$$V_{ff} = \frac{e N_{DL}^* d^2}{\varepsilon}$$

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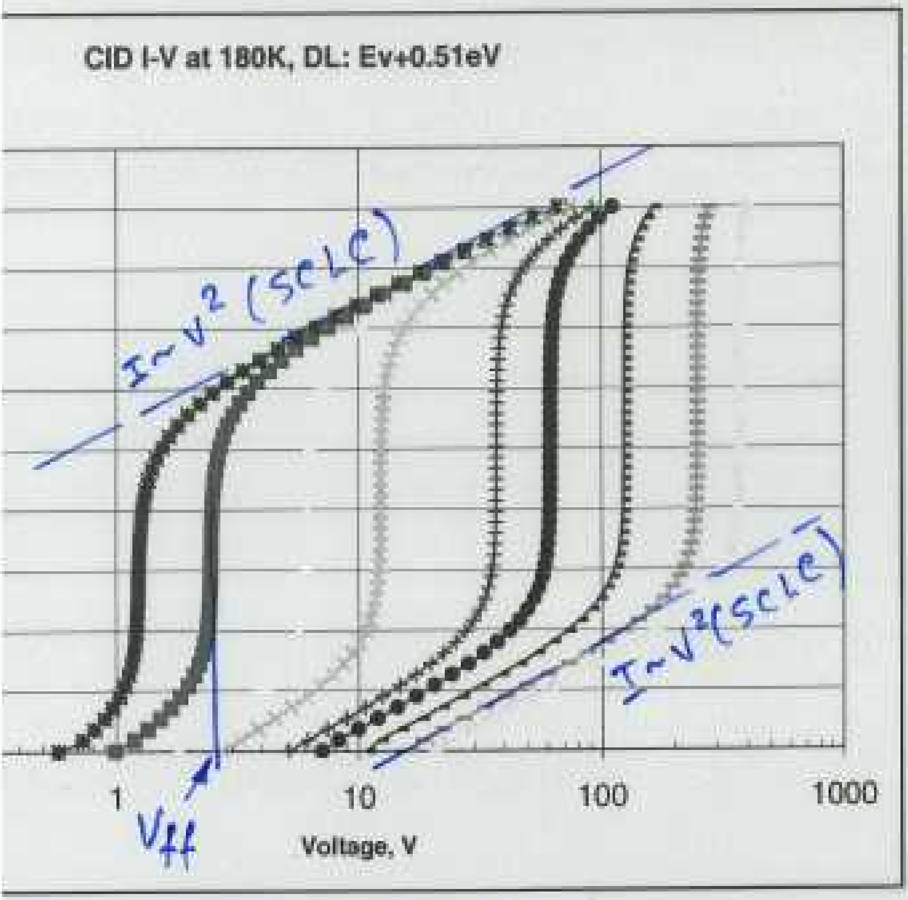
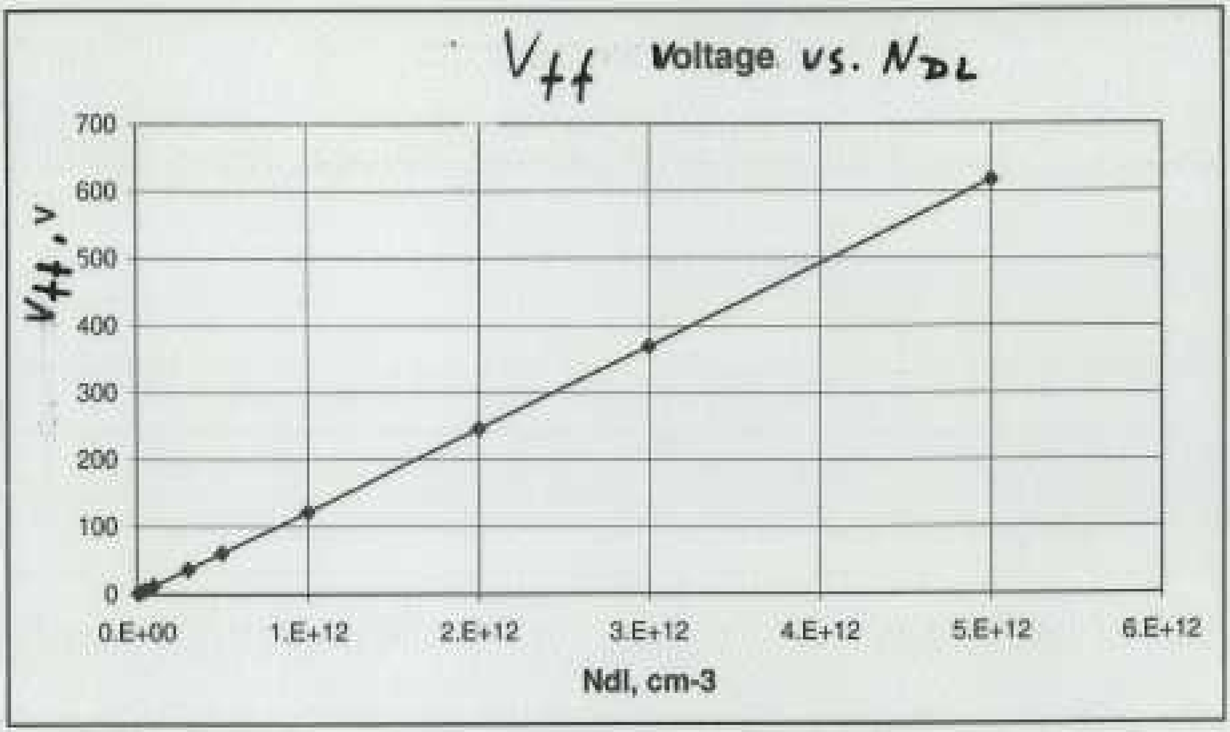
forward biased p^+-n-Ω CID



…oltage of DL full filling

…meters: T=180K, Ev+0.51 , d = 400μm

Ci-Oi		V-V		3		4	
0		1		0		1	
…ectrons	holes	electrons	holes	electrons	holes	electrons	holes
0.4		0.7		0.51	0.61	0.55	0.57
…00E-15		1.00E-17		1.00E-15		5.00E-15	
	1.00E-15		1.00E-15		1.00E-15		5.00E-15



$$V_{tf} \simeq \frac{e N_{DL}^{*} d^2}{\varepsilon}$$

! V_{tf} – maximum operational bias of CID

N_{DL} – non occupied fraction of DL

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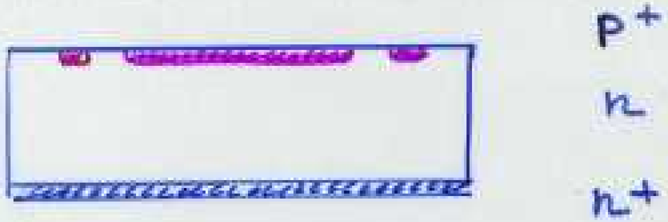
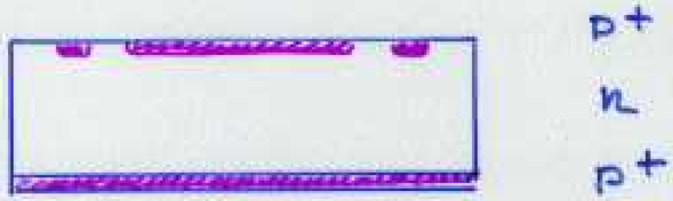
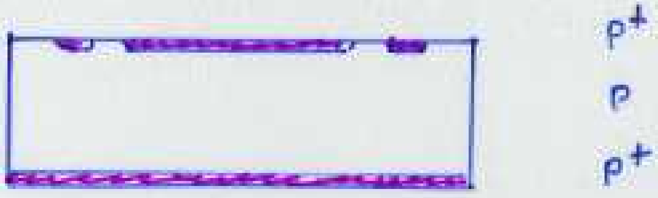
Detector structures







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Irradiation

Protons 24 GeV

Run #	Φ_p cm^{-2}
218	$6.8 \cdot 10^{10}$
214	$1.08 \cdot 10^{14}$
215	$3.2 \cdot 10^{14}$
216	$5.58 \cdot 10^{14}$
217	$8.63 \cdot 10^{14}$
213	$3.75 \cdot 10^{15}$

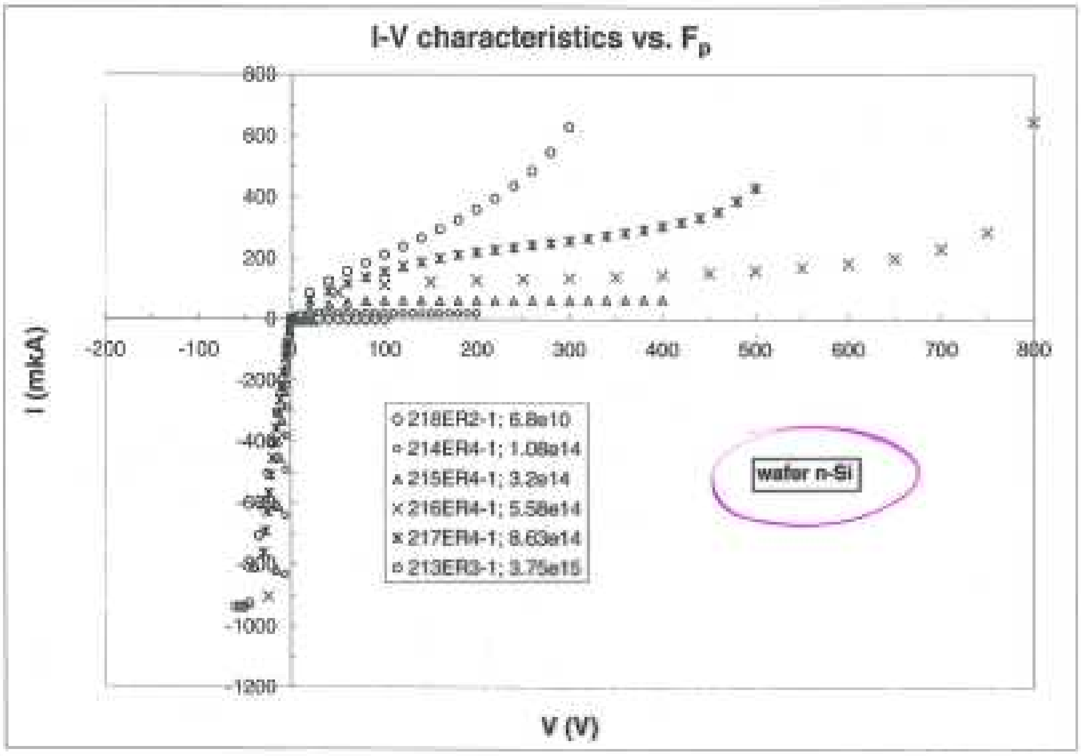
Beneficial annealing:

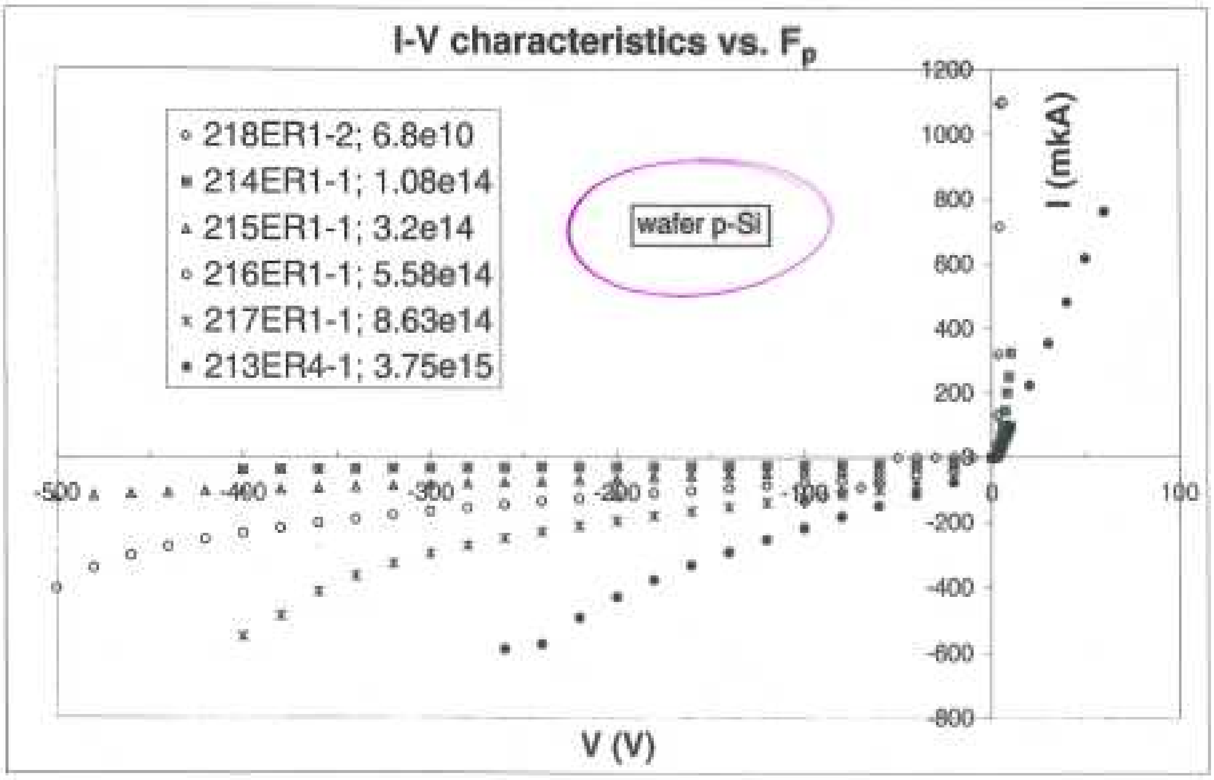
80° : 3 min

RT-evaluation
- C-V
- I-V

RT - I-V curves

• p-n junction detectors





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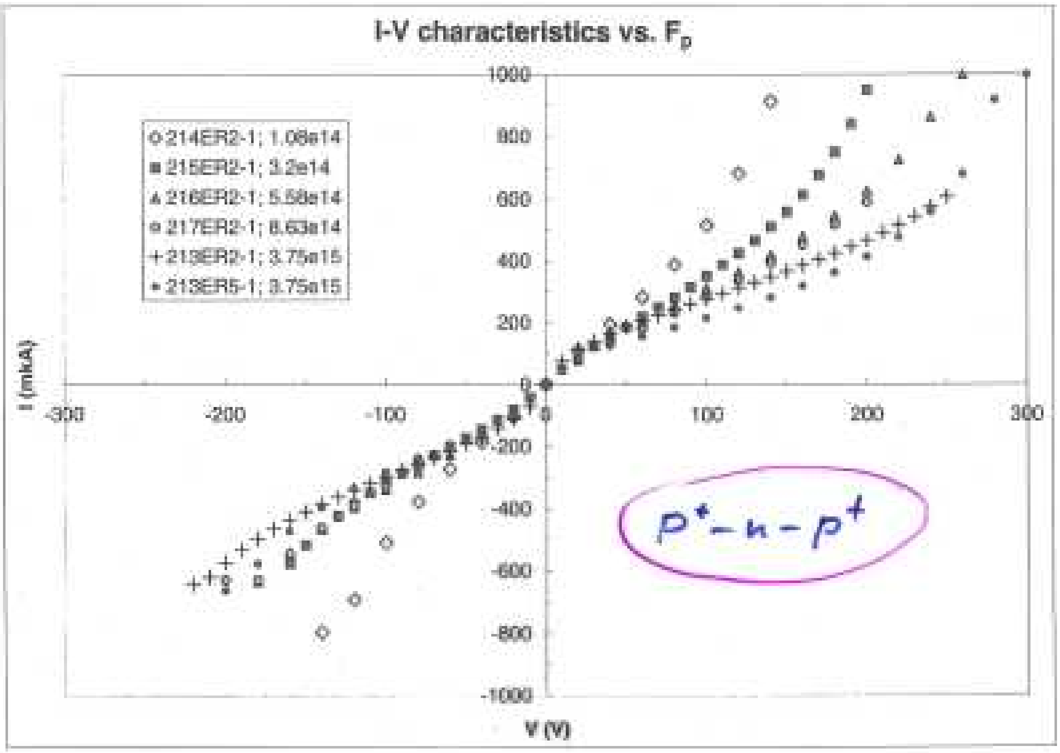
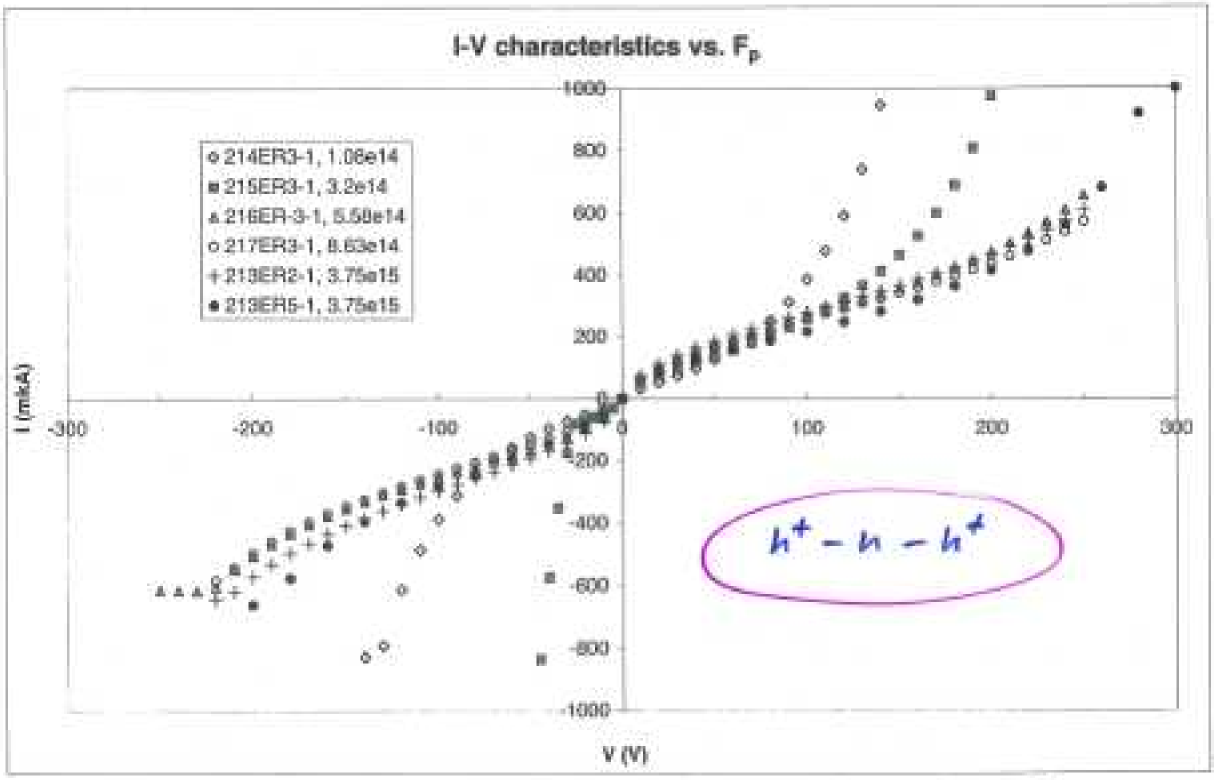
RT - I-V curves

Symmetric structures





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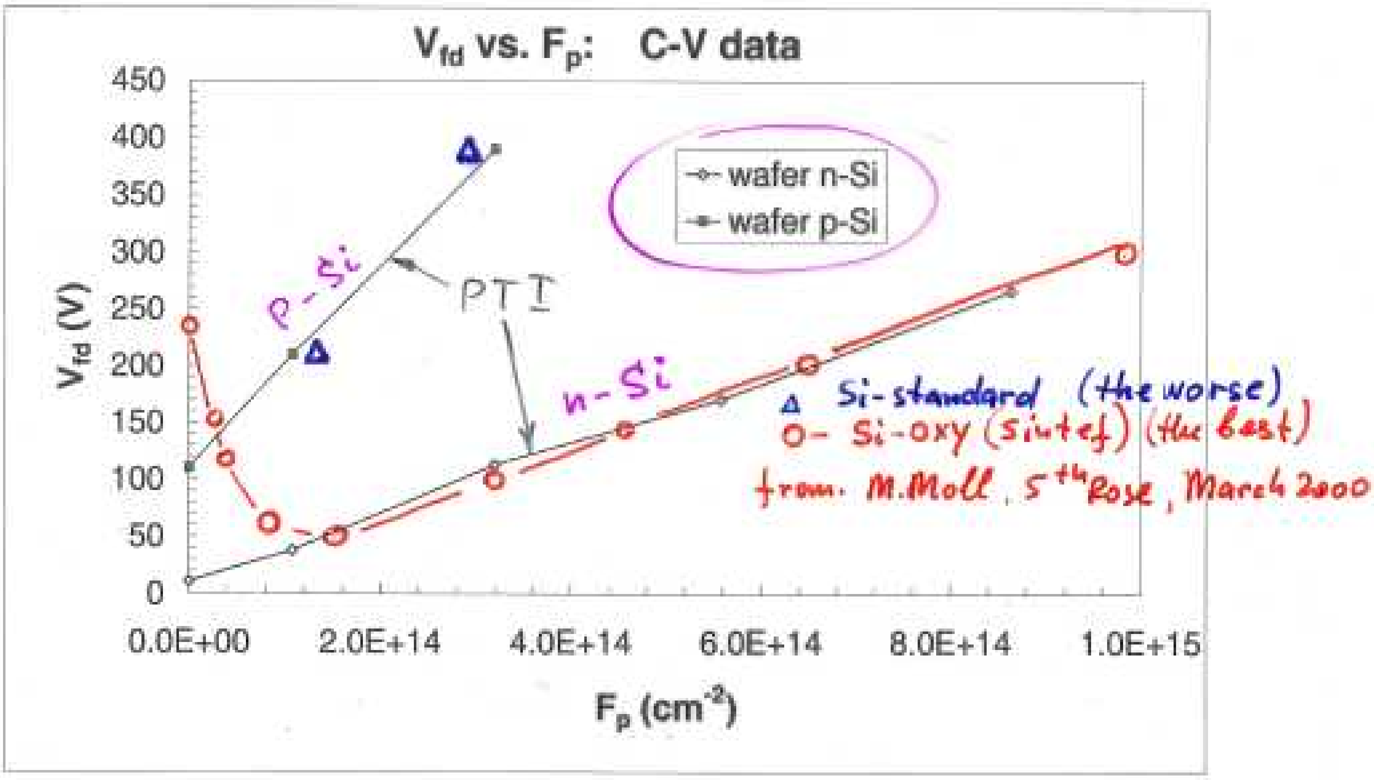
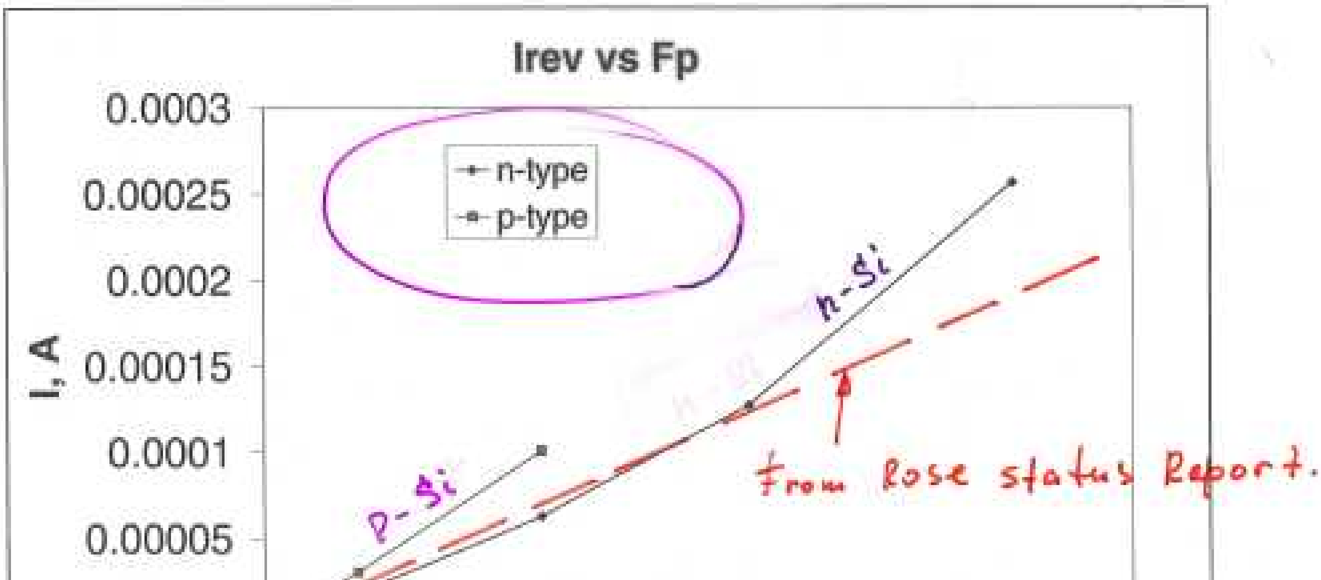
V_{fd} and I_r degradation with Φ_p





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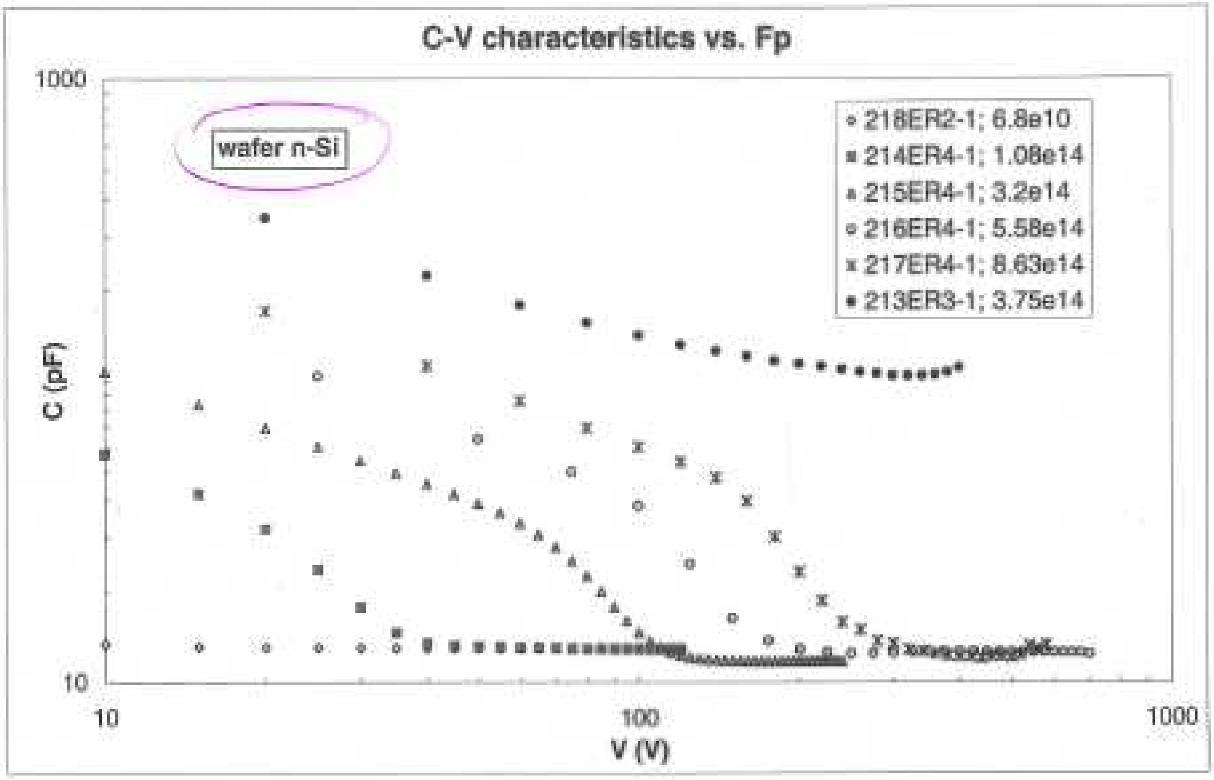
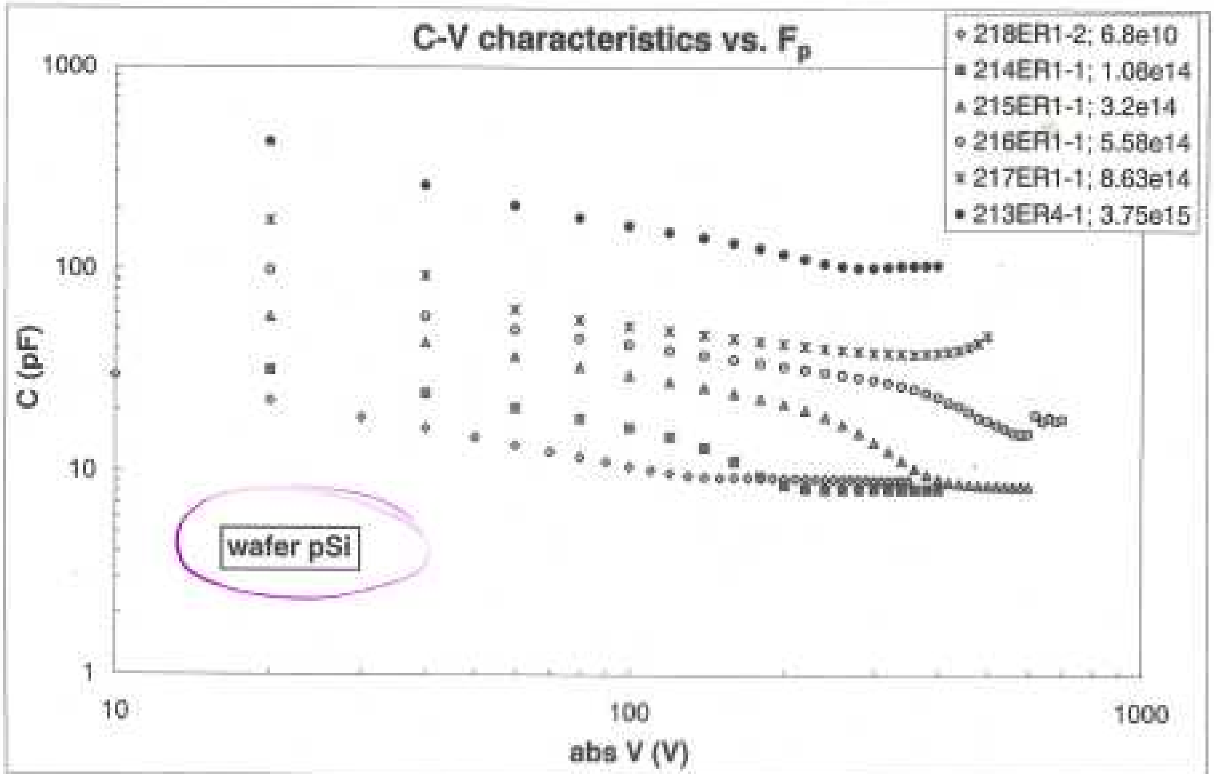
RT - C-V characteristics

p-n junction detectors





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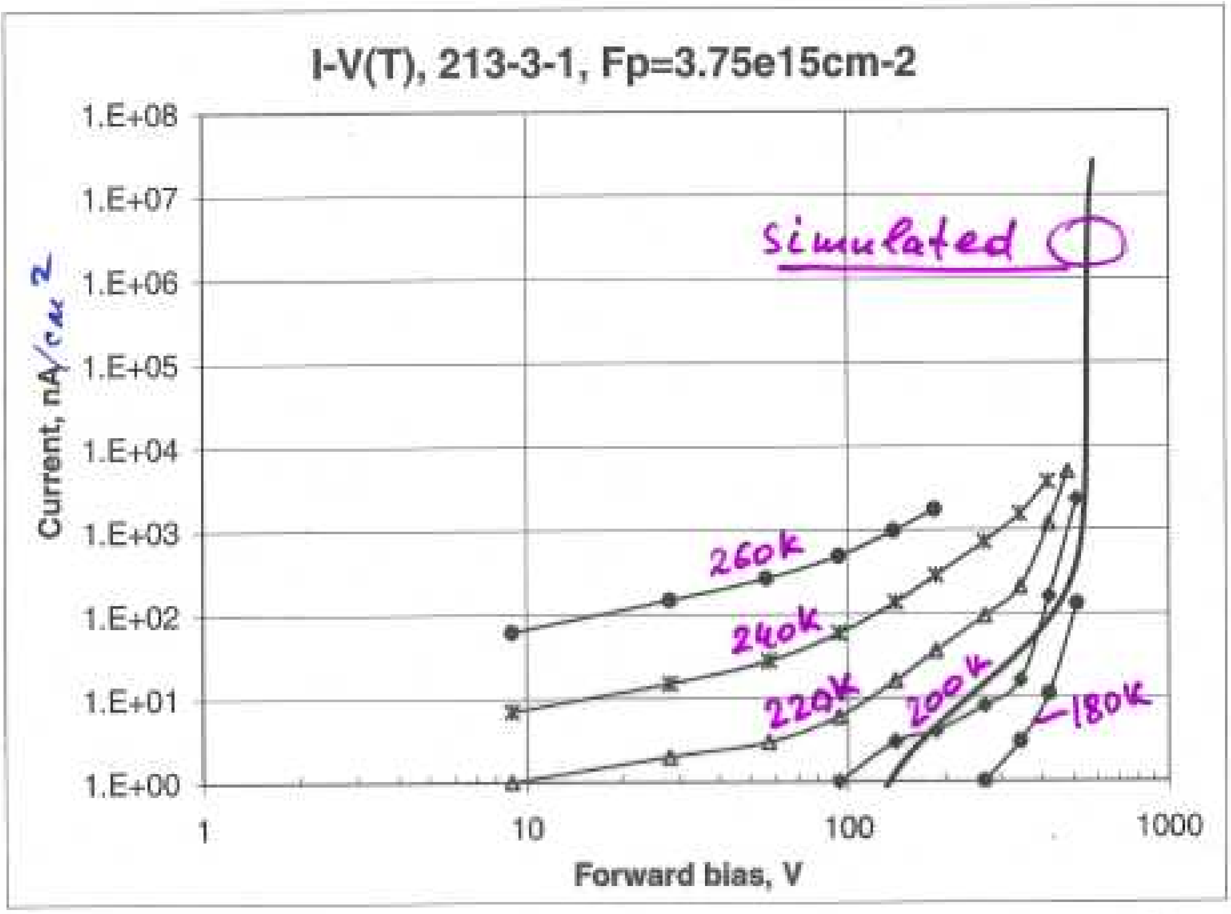
Forward I-V characteristics

- experiment
- simulation



Parameters for simulation:

DL: donor, $\sigma_n = \sigma_p = 10^{-15}\ cm^{-3}$, $E_v + 0.537\ eV$

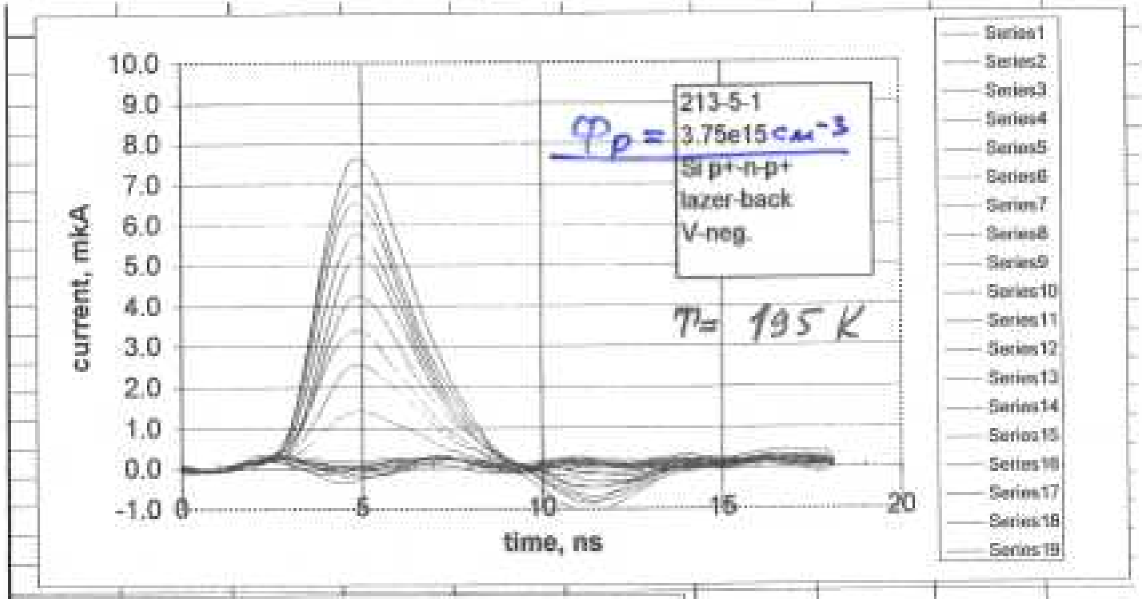
$N^*_{DL} = 4.5 \cdot 10^{12}\ cm^{-3}$

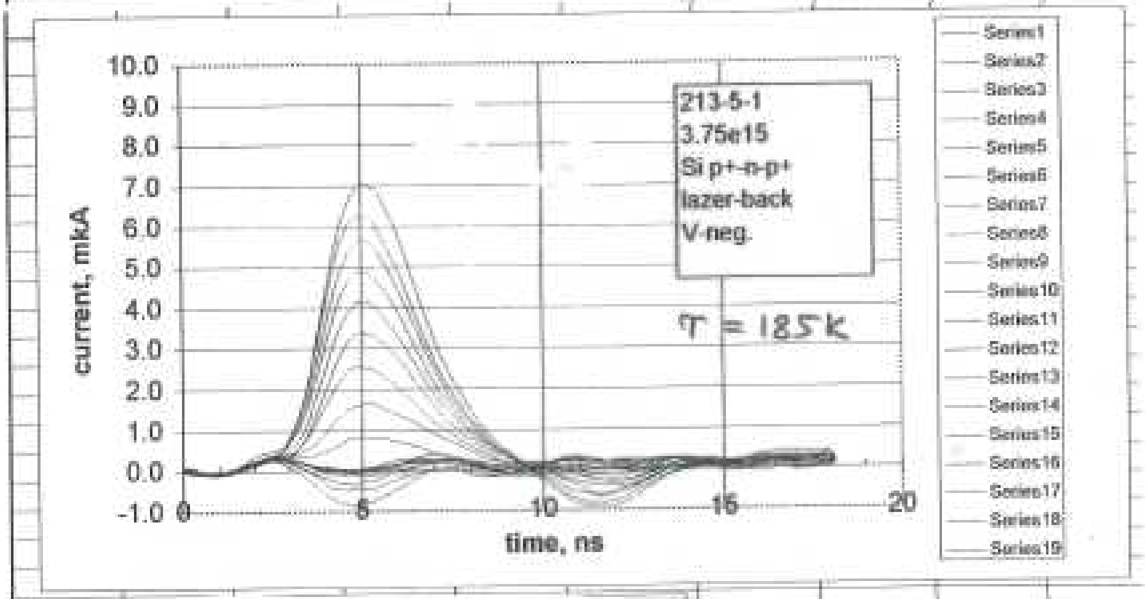
$T = 200\ k$

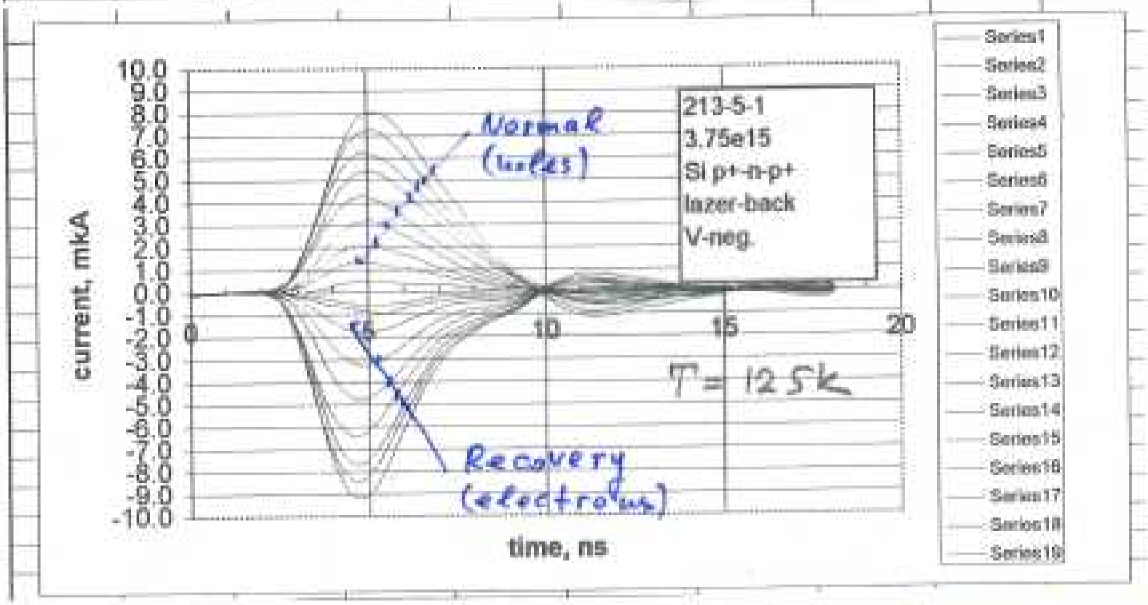
$d = 400\ \mu m$.

Current responce for p-n junction reverse biased detector

hole collection







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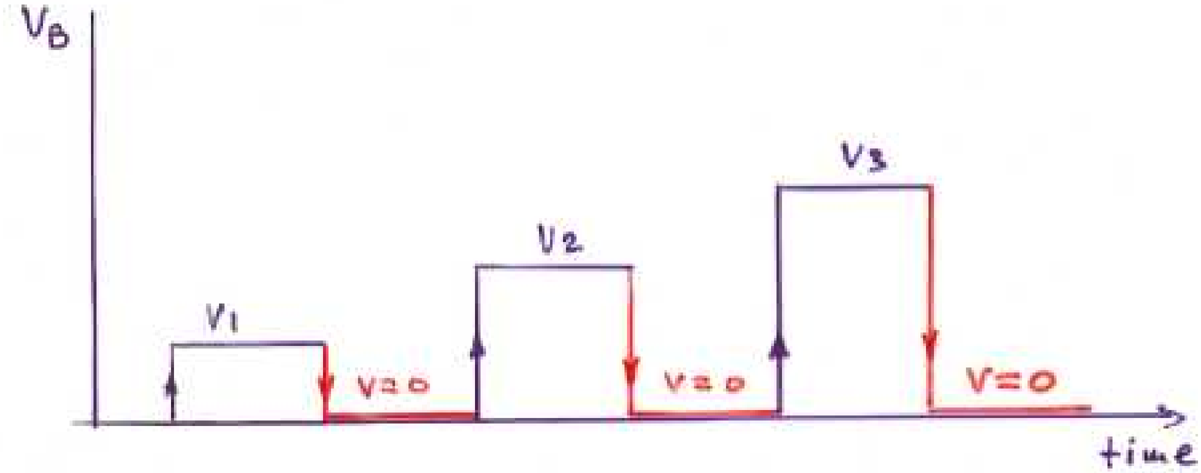
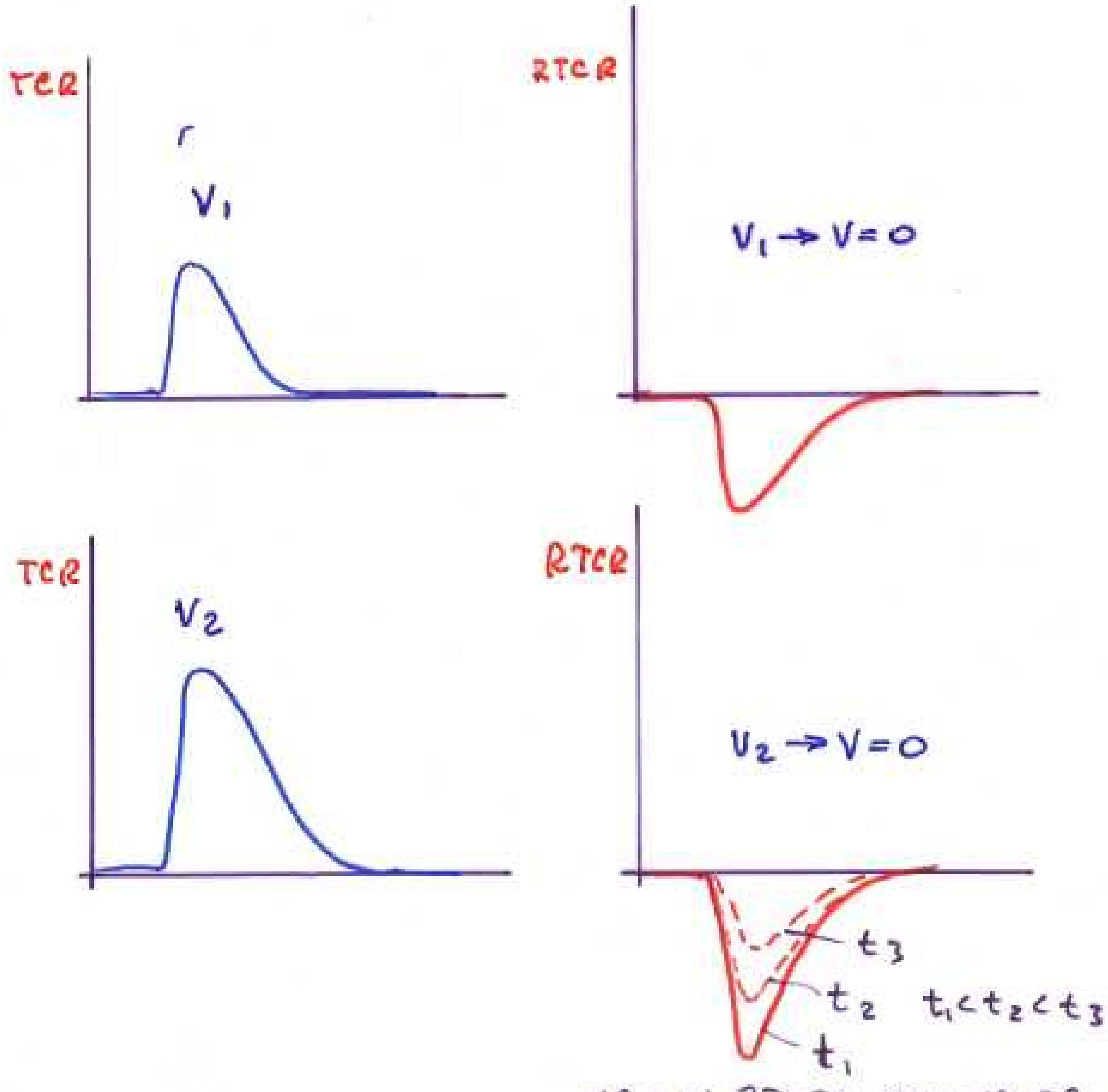
Transient Current Responce (TCR) and Recovery Transient Current Responce (RTCR)





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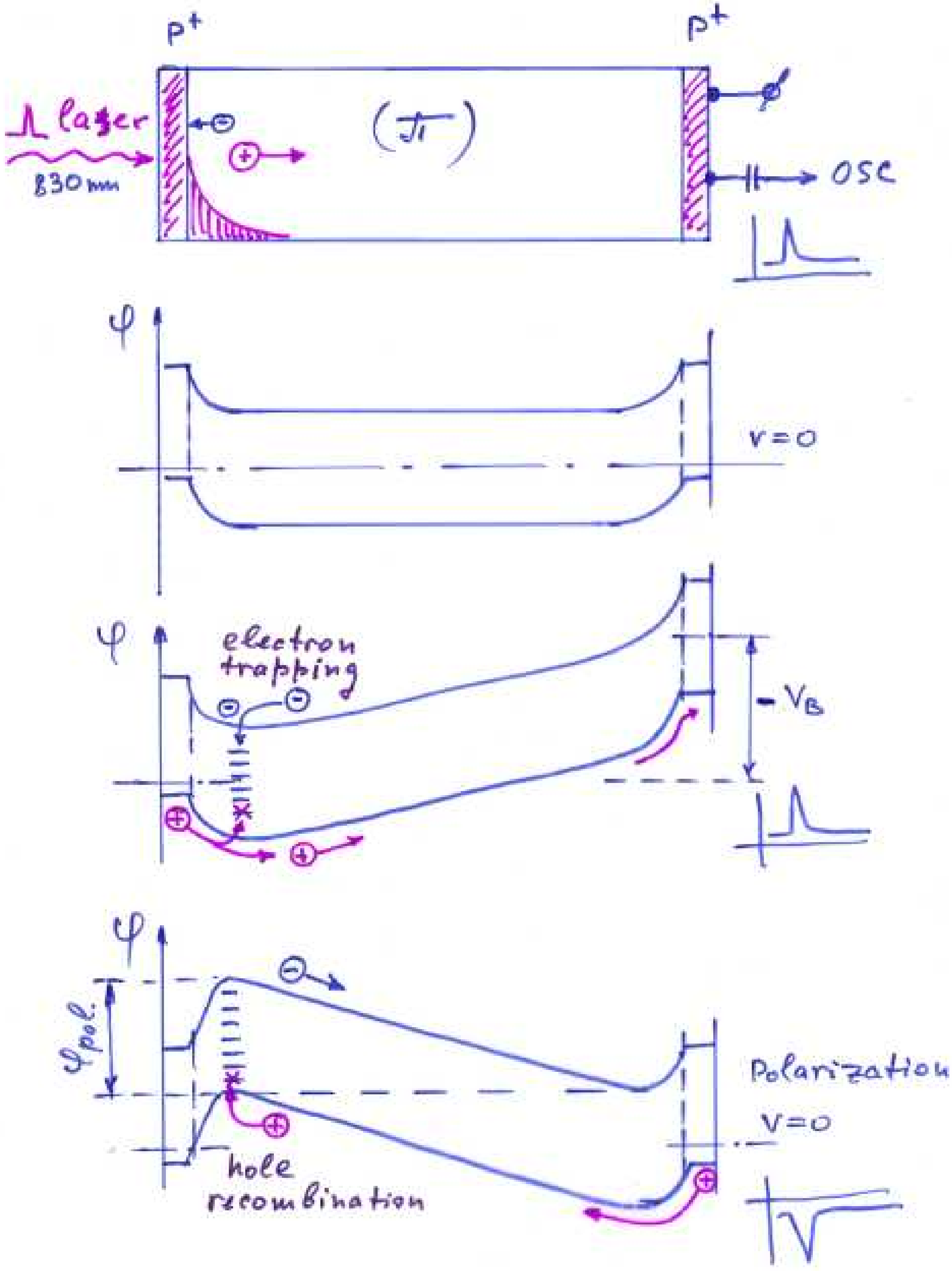
Polarization of p⁺-n-p⁺ detectors



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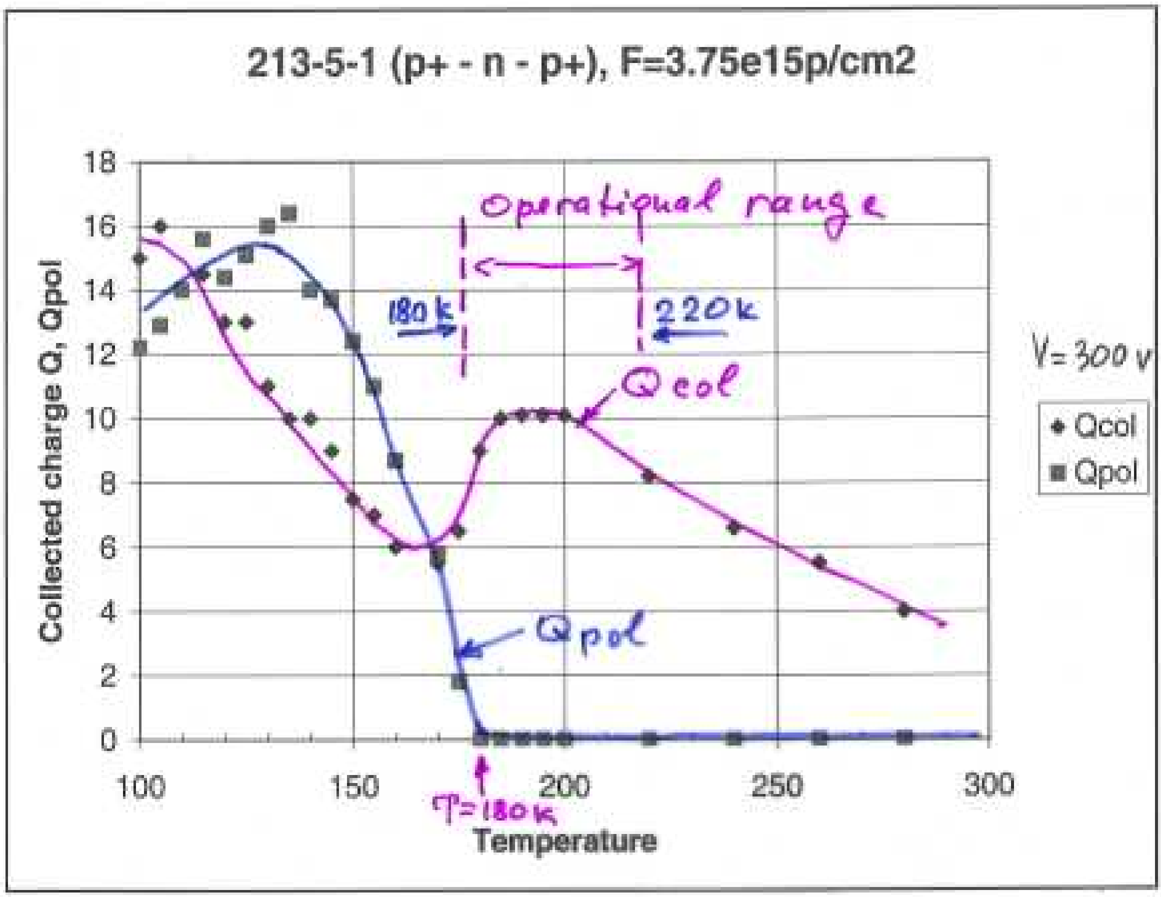

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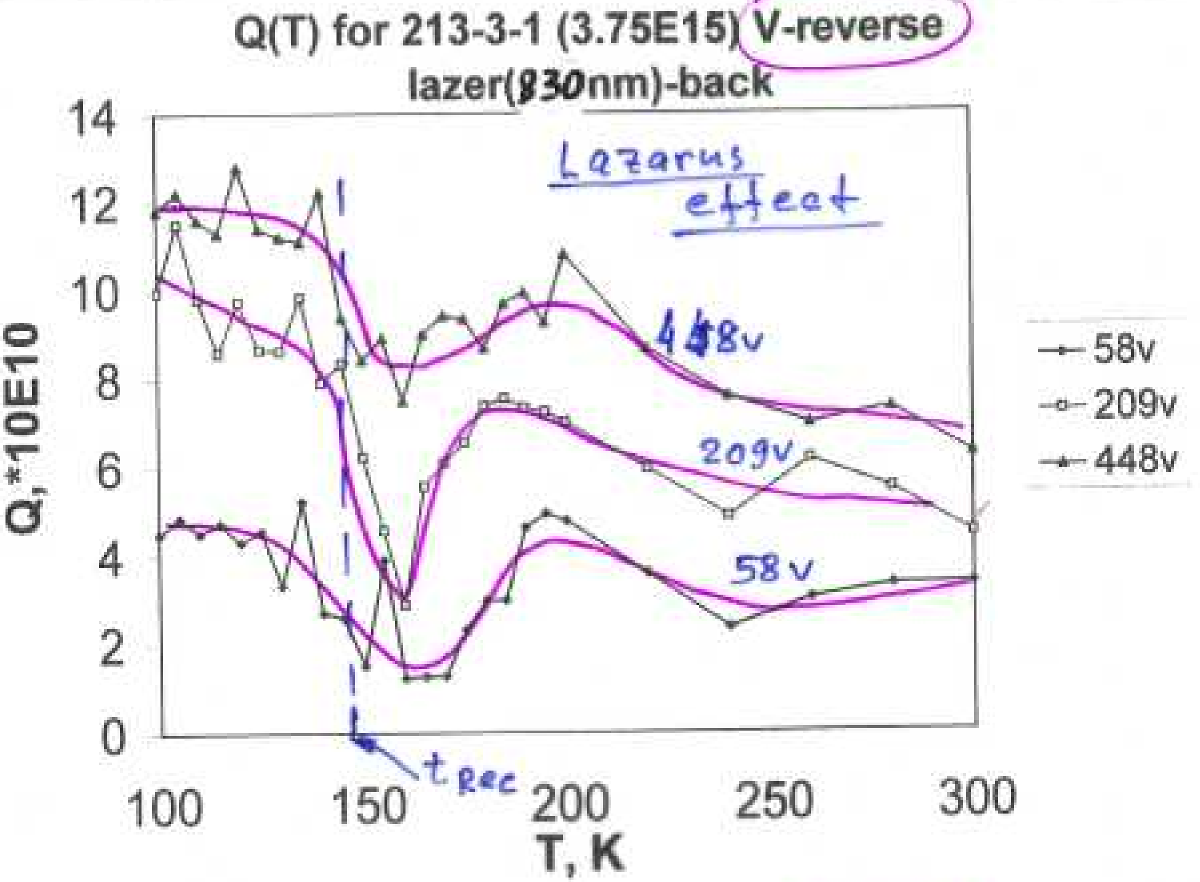
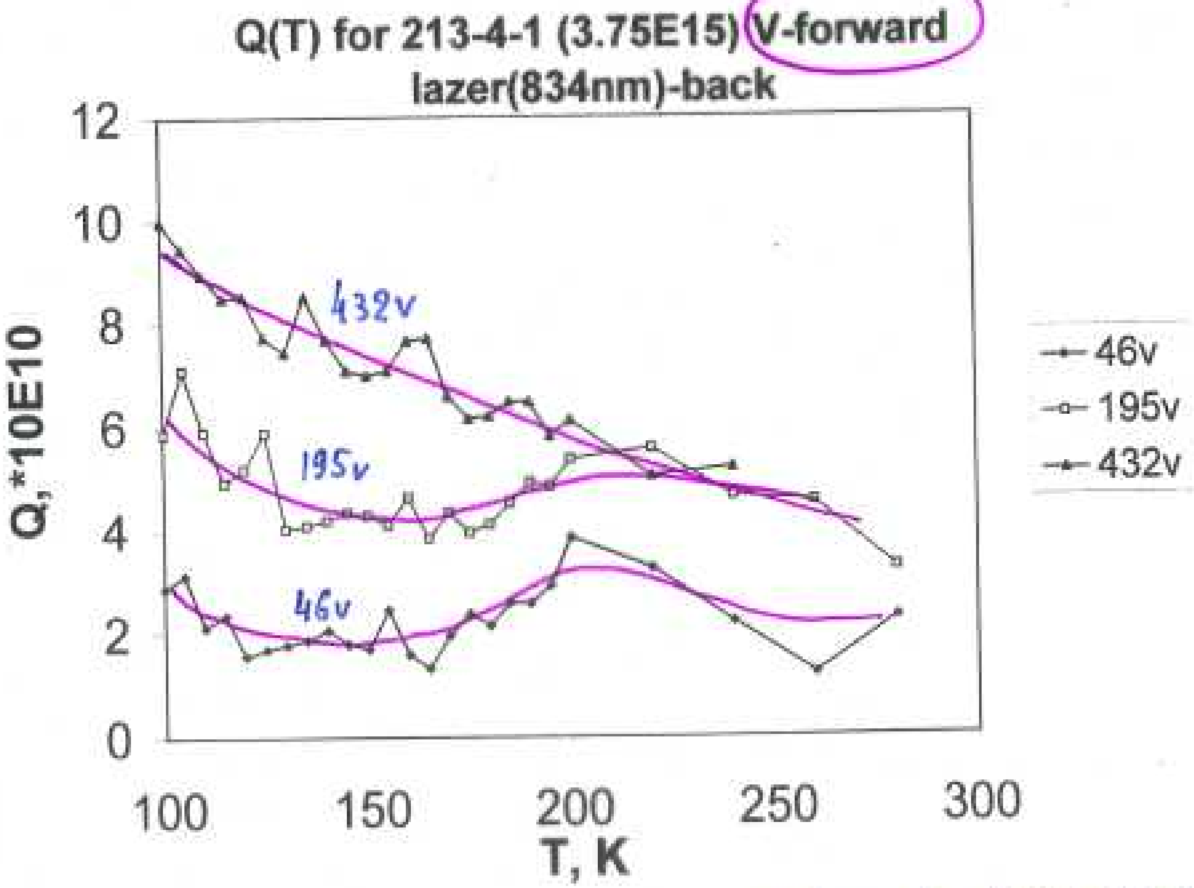
Collected charge in p-n junction detectors





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Conclusions

1. The simple model allows to define the major operational parameters of CID
   - V_{max}
   - $I_{operational}$
   - $E(x)$

2. The first observation of SCLC in silicon irradiated p-n junctions

3. The model gives a way to extract the value of non charged fraction of DL

4. The rest questions:
   - CCE for MIPs
   - where is a double side injection??

5. The advantages of p^+-n-p^+ CID:
   - positive (regular) polarity of signal
   - compatibility with regular electronics
   - appropriate operational temperature range.

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