First results on electric field distribution in irradiated epi-Si detectors

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Outline

1. Background: E(x) distribution in heavily irradiated detectors

2. Approach for simulation of detector Double Peak response and E(x) profile reconstruction with a consideration of electric field in the "neutral" base

3. Experimental current pulse response in epi-Si SMART detectors irradiated by 1 MeV neutrons and 26 MeV protons and E(x) profiles

4. E(x) profiles in epi-Si detectors reconstructed from current pulse response

Conclusions

Electric field distribution in heavily irradiated Si detectors

- **Heavily irradiated detector: Double Junction (DJ) structure:**

  Z. Li, H. W. Kraner, IEEE TNS 39 (1992) 577

- **Two depleted regions and a neutral base *in-between***

  D. Menichelli, M. Bruzzi, Z. Li, V. Eremin, NIM A 426 (1999) 135

- **Two depleted regions and a base *in-between* with electric field due to potential drop over high resistivity bulk**

  E. Verbitskaya et al. NIM A 557 (2006) 528-539; "Concept of Double Peak electric field distribution in the development of radiation hard silicon detectors; pres. RESMDD'6, NIM A (in press)

Experimental verification:

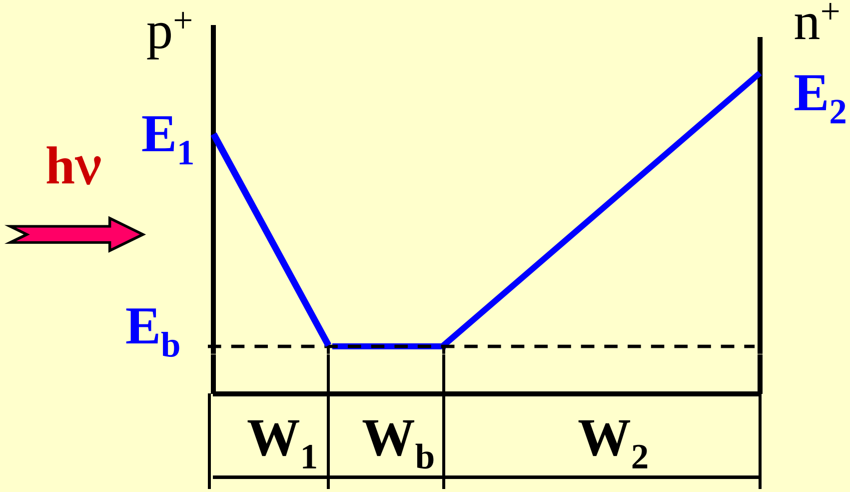
A. Castaldini, A. Cavallini, L. Polenta, F. Nava, C. Canali, NIM A476 (2002) 550

Approach for simulation of detector Double Peak response and E(x) profile reconstruction with a consideration of electric field in the "neutral" base

Initiated by PTI, developed in:

1) E. Verbitskaya et al. NIM A 557 (2006) 528;
2) E. Verbitskaya, Concept of Double Peak electric field distribution in the development of radiation hard silicon detectors; pres. RESMDD'6, NIM A (in press)

- Three regions of heavily irradiated detector structure are considered
- **Reverse current flow creates potential difference and electric field in the neutral base**

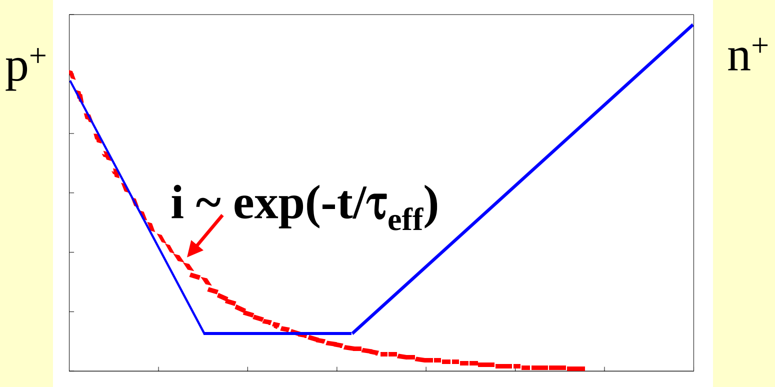


Transient current:

$$i(t) = \frac{Q_o \mu E}{d} e^{-t/\tau_{tr}}$$

$$\tau_{tr} = \frac{1}{\sigma v_{th} N_{tr}} \qquad N_{tr} = f(F)$$

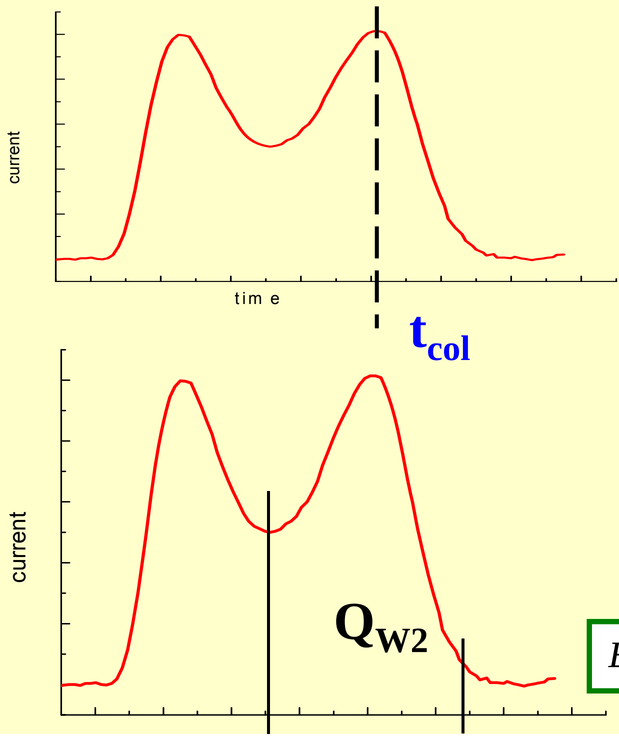
Simulation of detector Double Peak response and E(x) profile reconstruction with a consideration of electric field in the "neutral" base



Signal due to carrier drift in W_1 is independent on the properties of W_b and W_2

$i = i_1 \sim \exp(-t/\tau_{tr})$

$\Rightarrow W_1, N_{eff1}, E_1$



t_{col}: depends on E_b and W_b

$\Rightarrow E_b, W_b$

Charge collected inside W_2

$Q_{W2} = Q_o(d - W_1 - W_n)/d$

$\Rightarrow W_b, W_2, E_2, N_{eff2}$

$\int Edx = V$

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New development of E(x) profile reconstruction with a consideration of electric field in the "neutral" base

Special algorithm and software are developed which give direct calculation of the electric field distribution

♦ Current pulse response is considered as drift current

$$i(t) = en\mu E(x)$$

♦ Correction for carrier trapping is done

$$i(t)_{corr} = i(t) \cdot \exp\left(t / \tau_{tr}\right)$$

♦ $\tau_{\tau r}$ is parameter dependent on fluence

♦ $\int \mathbf{E}dx = V$ **at x = d**

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Current pulse response in irradiated epi-Si SMART detectors

Detectors: SMART, p+ - n-epi Si - n+ wafer

Epi-layer thickness: 150 μm

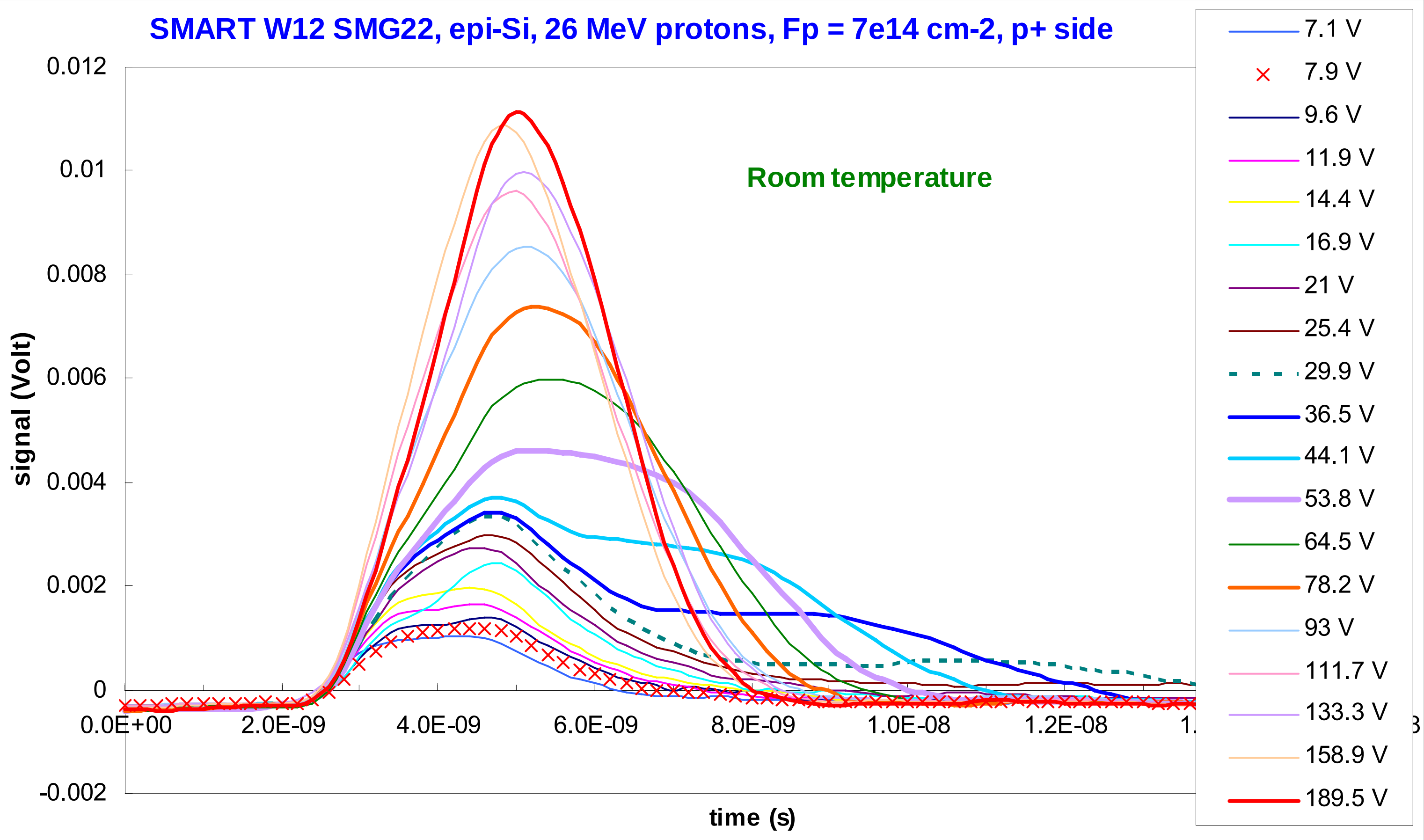
#	irradiation	equiv. fluence (ci	annealing	
			T	time (min)
W12 SMG22	26 MeV protons	7.00E+14	80C	60
W13 SMG 15	1 Mev Neutrons	8.50E+14	no annealing	
W12 SMG 15	1 Mev Neutrons	8.50E+14	80C	60

Experimental Technique: TCT setup at Ioffe Institute

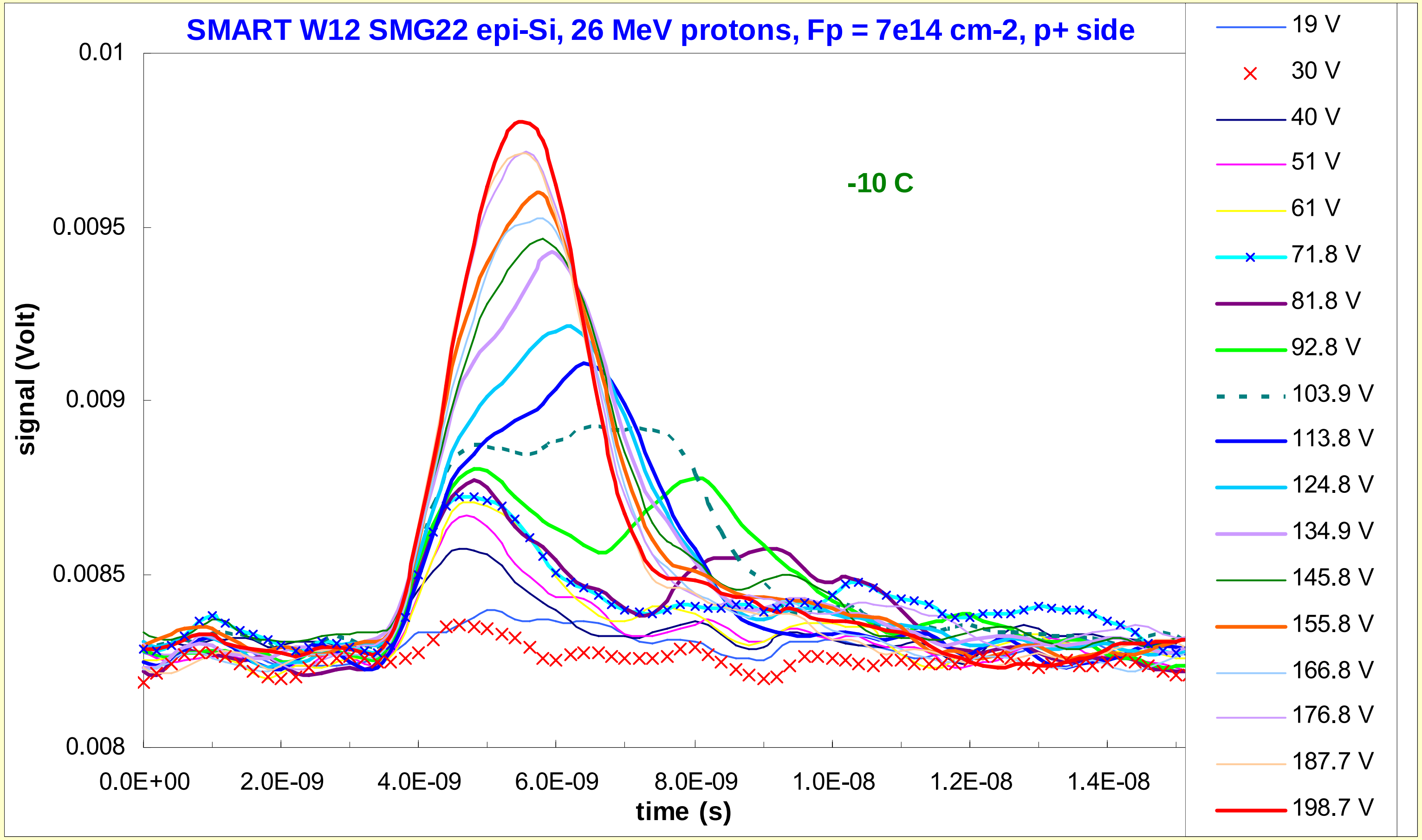
TCT setup response	0.8 ns
Temperature range	77 – 373K
Laser wavelength	830 μm

All experiments: Laser at p+ side: electron collection

Current pulse response in proton irradiated epi-Si SMART detectors



Current pulse response in proton irradiated epi-Si SMART detectors



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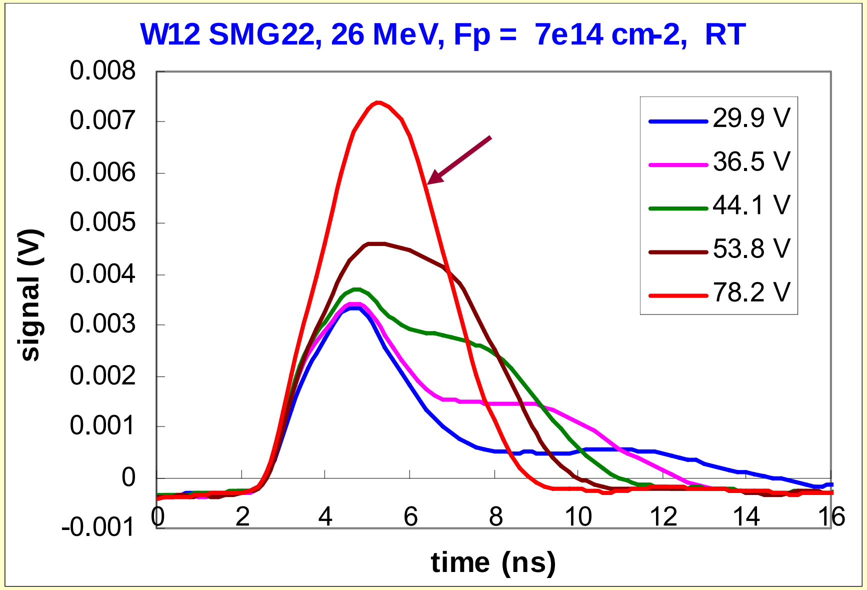
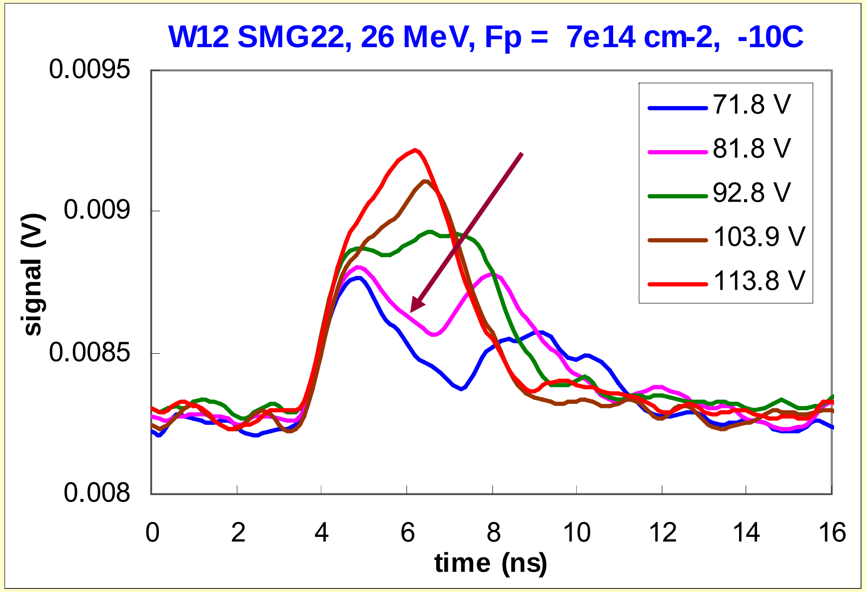
Current pulse response in proton irradiated epi-Si SMART detectors

26 MeV protons, F_p = 7e14 cm^{-2}





Full depletion at -10C occurs at higher V

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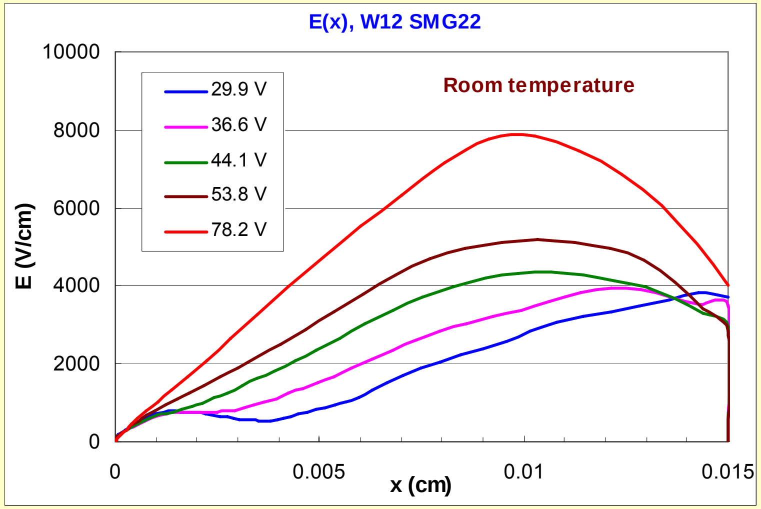
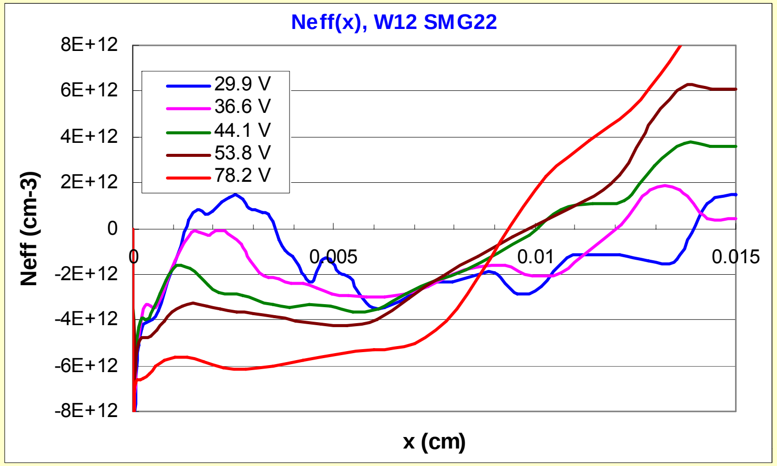
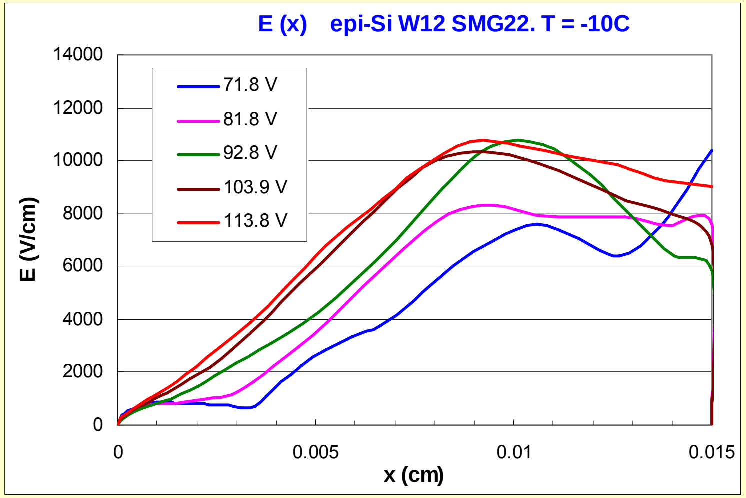
$E(x)$ and $N_{eff}(x)$ profiles in proton irradiated epi-Si detectors

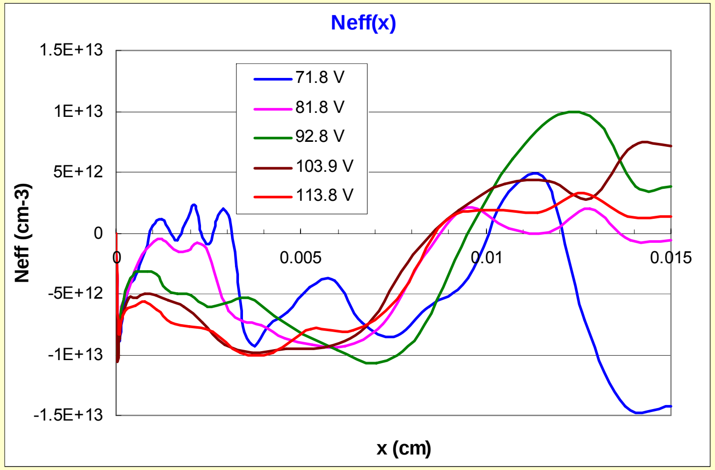
RT





T = -10C





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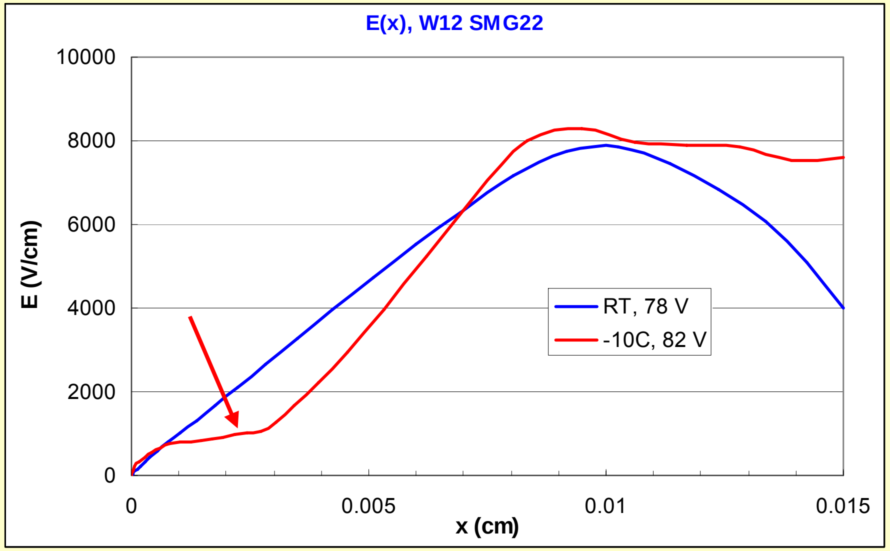
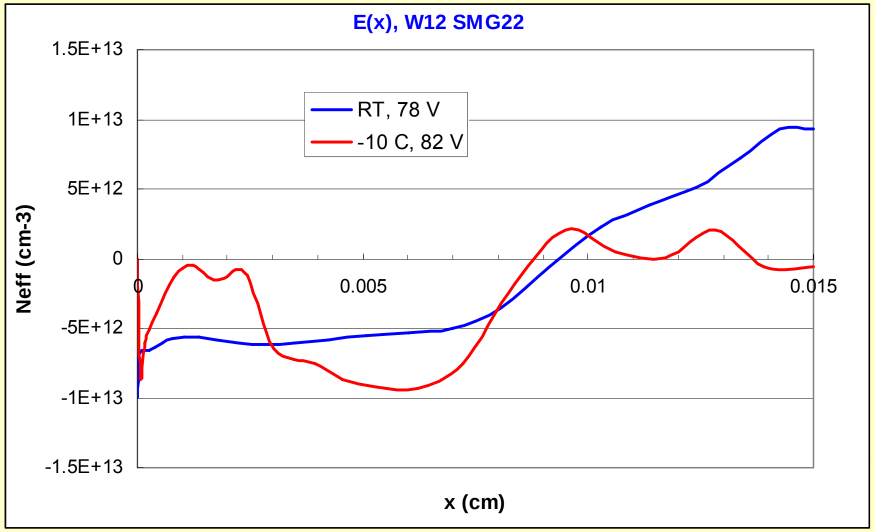
E(x) and N_{eff}(x) profiles: comparison at different temperatures





Base region exists near the p+ contact:

RT: V≤40 V

-10C: V≤80 V

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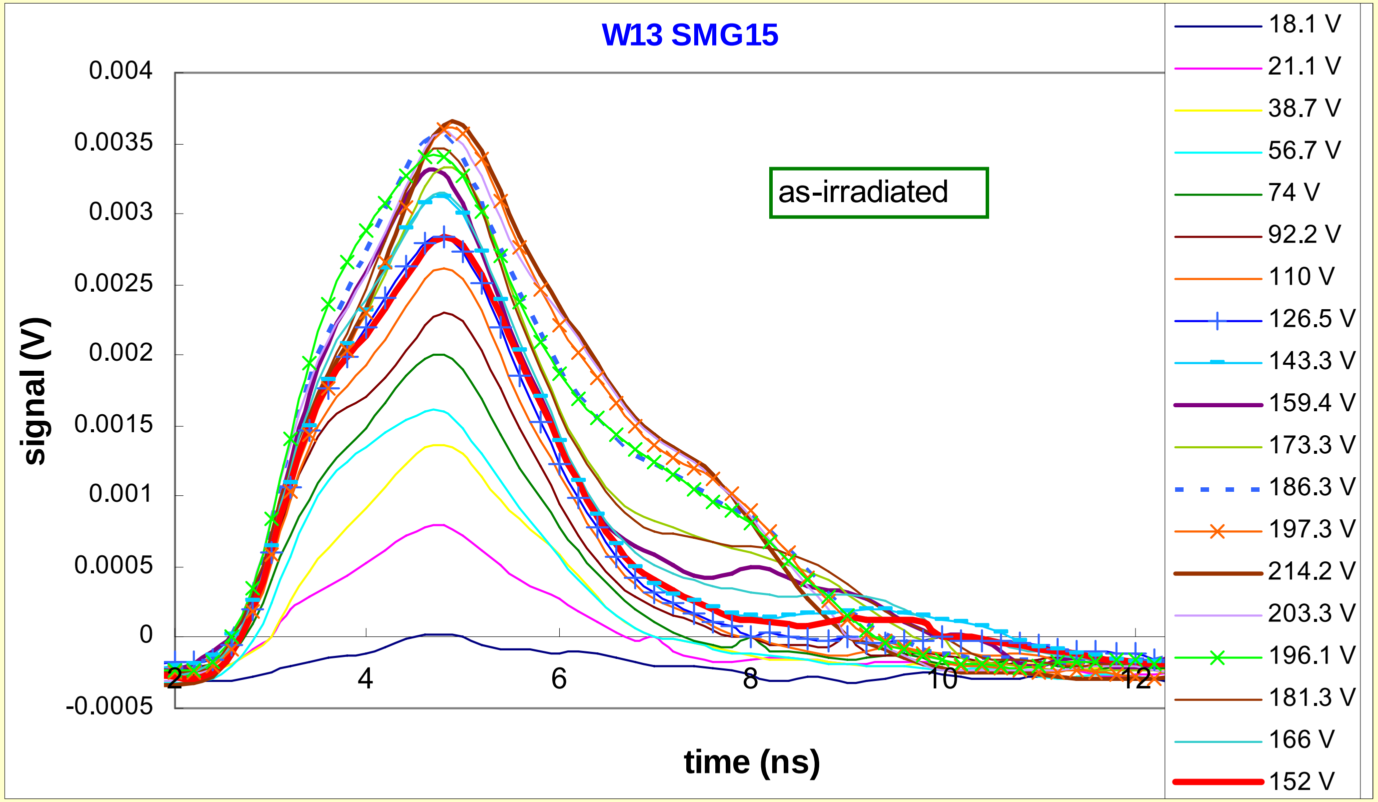
Current pulse response in neutron irradiated epi-Si SMART detectors

W13 SMG15, F_n = 8.5·10^{14} cm^{-2}, as-irradiated



Reverse current is significant at V>200 V

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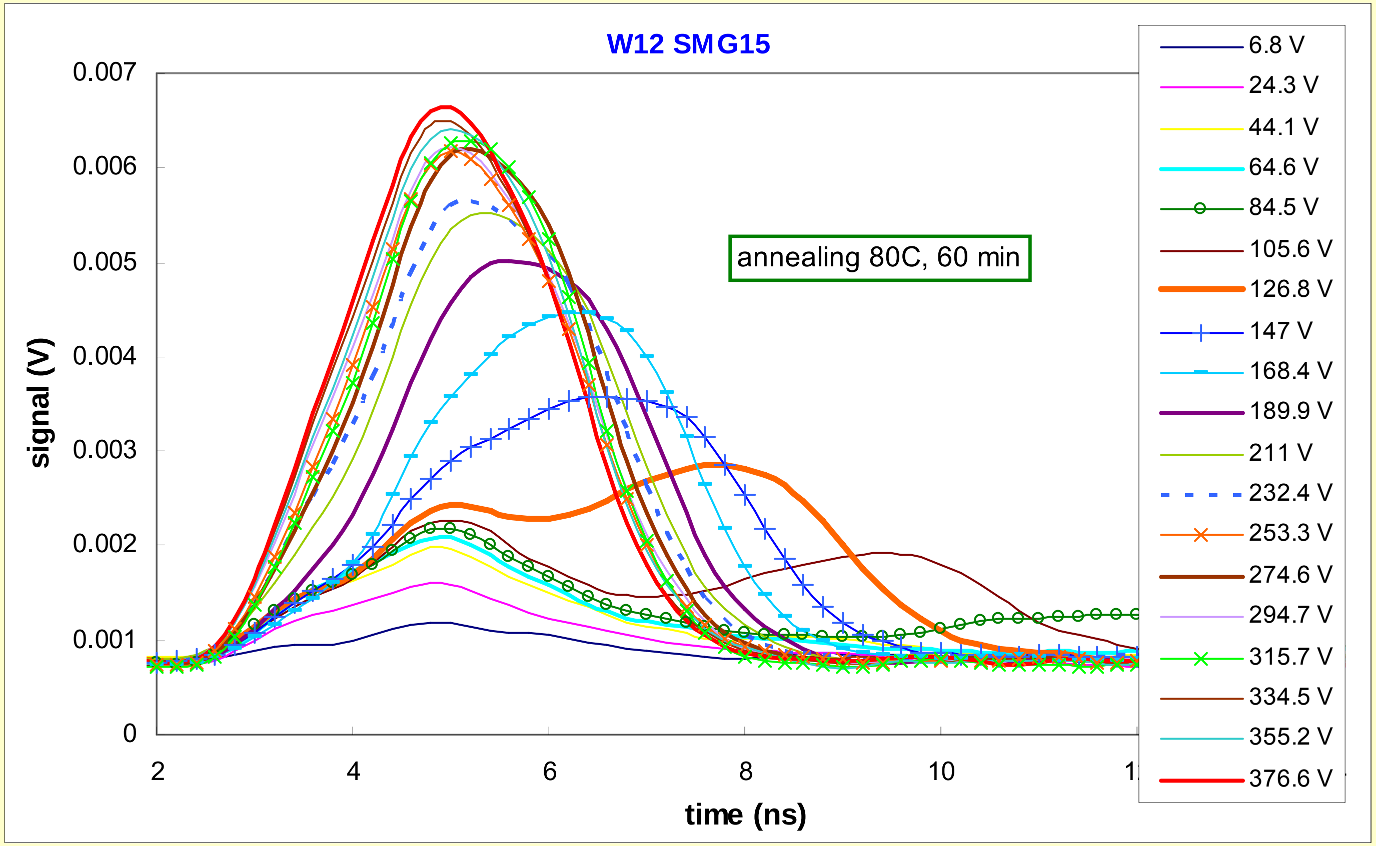
Current pulse response in neutron irradiated epi-Si SMART detectors

W12 SMG15, $F_n = 8.5 \cdot 10^{14}$ cm^{-2}, annealed 80C, 60 min



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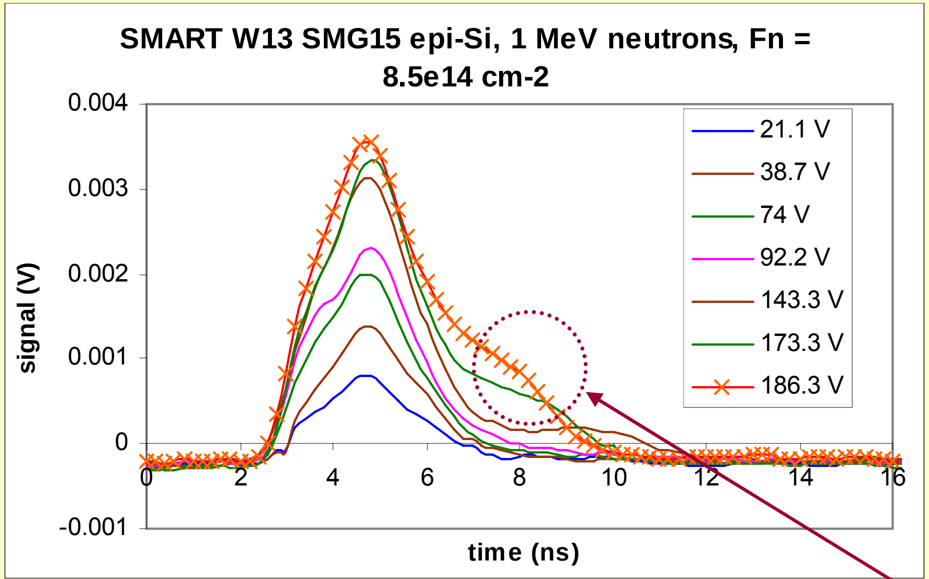
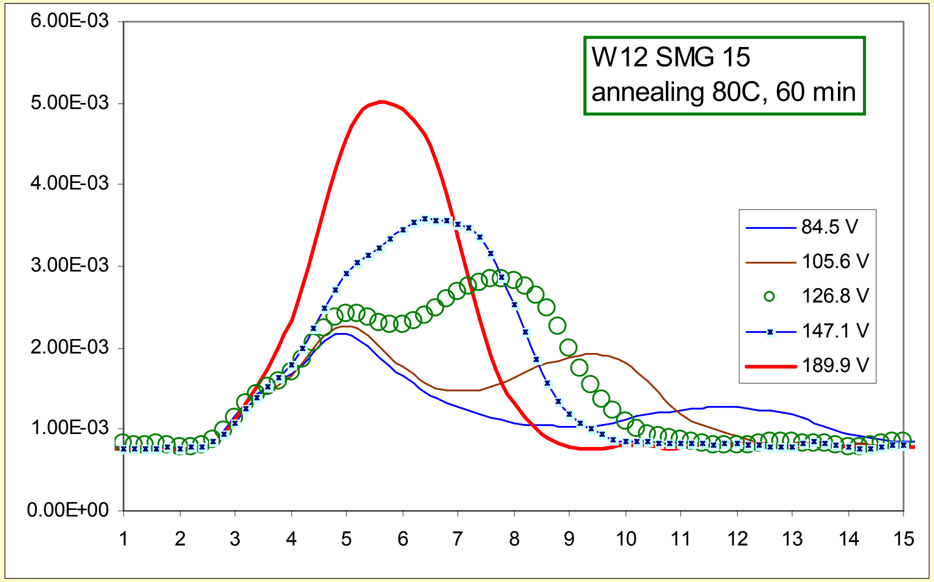
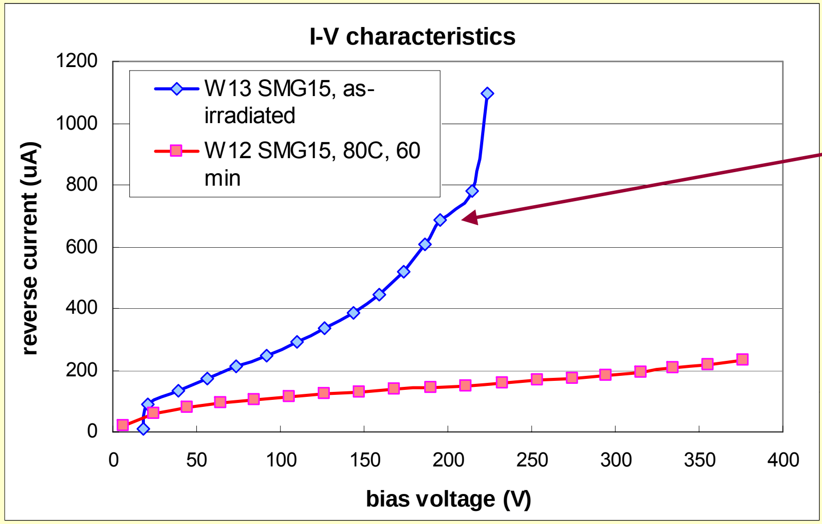
Current pulse response in neutron irradiated epi-Si detectors







♦ Annealing results in significant reduction of current.

♦ Increase of electric field near the **interface wafer-epi-layer** due to carrier trapping from enhanced current at higher V?

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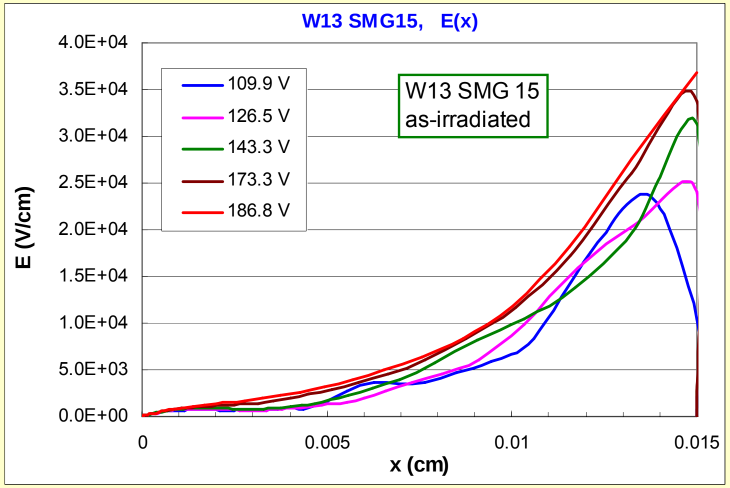
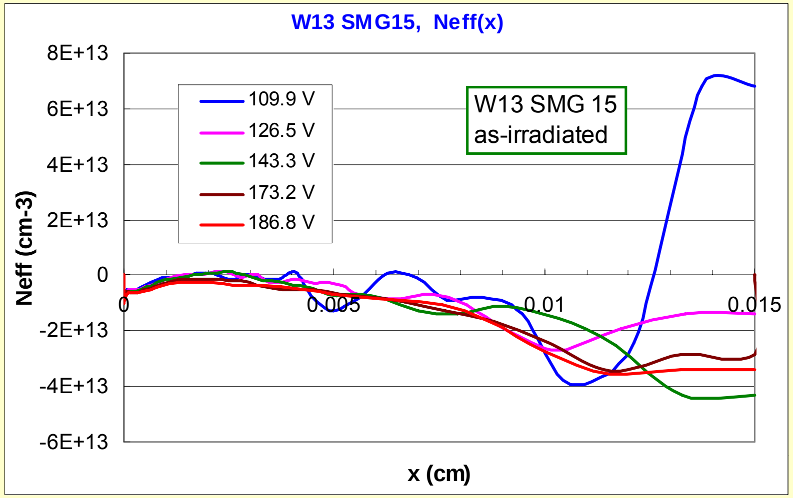
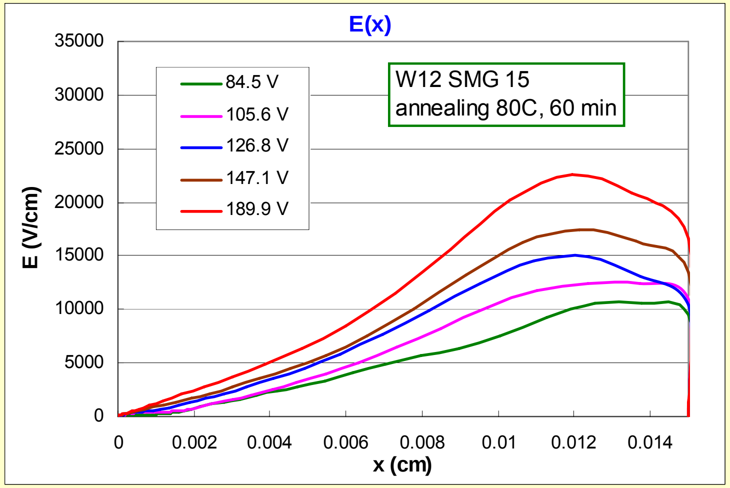
E(x) and N_{eff}(x) profiles in neutron irradiated epi-Si detectors

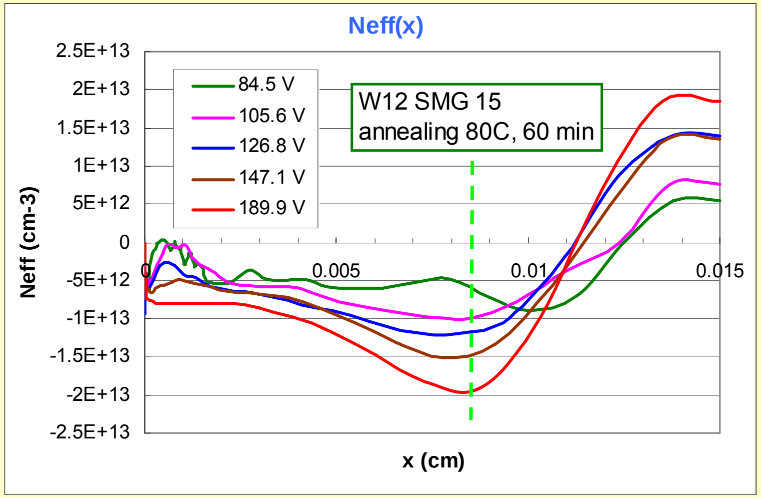
W13 SMG15, *as-irradiated*





W12 SMG15, *anneal 80C, 60 min*





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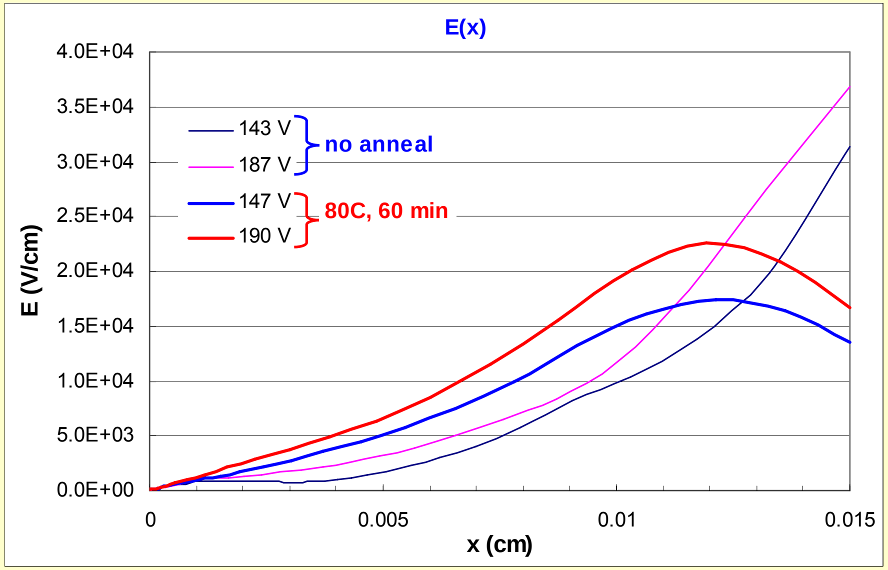
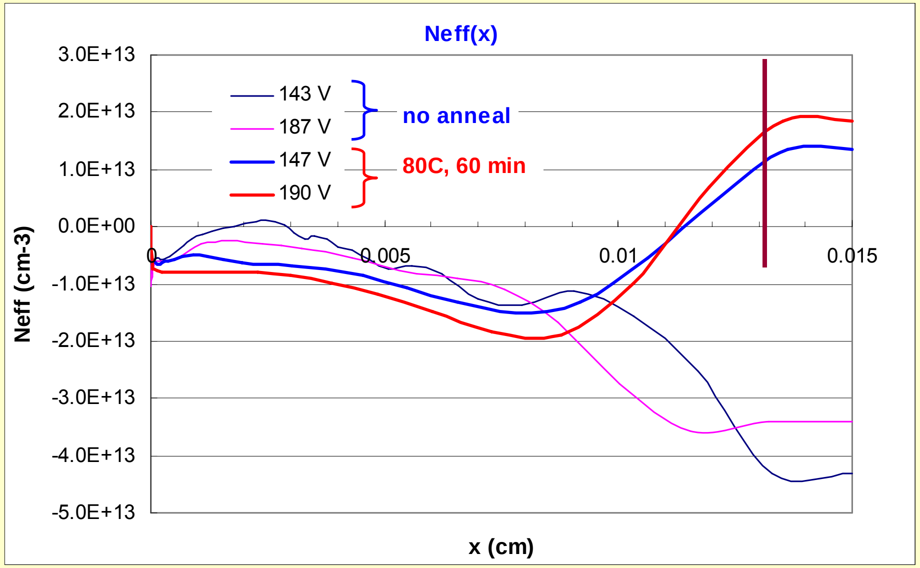
$E(x)$ and $N_{eff}(x)$ profiles: comparison of as-irradiated and annealed detectors

E(x)



$N_{eff}(x)$



- E at n+ contact is higher in as-irradiated detector
- Low field base region near p+ contact exists in both detectors, annealing doesn't eliminate it

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Trapping time constants

Proton irradiated, $7 \cdot 10^{14}$ cm^{-2}: 1.6-1.8 ns

Neutron irradiated, $8.5 \cdot 10^{14}$ cm^{-2}:

1.1 ns – as-irradiated
1.4 ns - annealed

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Conclusions

- *SCSI occurs in epi-Si detectors irradiated by 26 MeV protons and 1 MeV neutrons ($F = (7\text{-}8)\cdot 10^{14}$ cm^{-2}).*
- DP response in epi-Si irradiated detectors is related with base region rather than with DP E(x). Electric field in the base regions arises from current flow and potential drop over the base.
- Base region with rather high E (~few kV/cm) extends near the surface pf the epi-layer.
- As-irradiated detector – enhanced current and increase of electric field related to trapping at the n^+ contact? – needs additional study.
- New method of E(x) reconstruction in irradiated Si detectors is universal and is related to minimal number of parameters.

Acknowledgements

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Thank you for your attention!