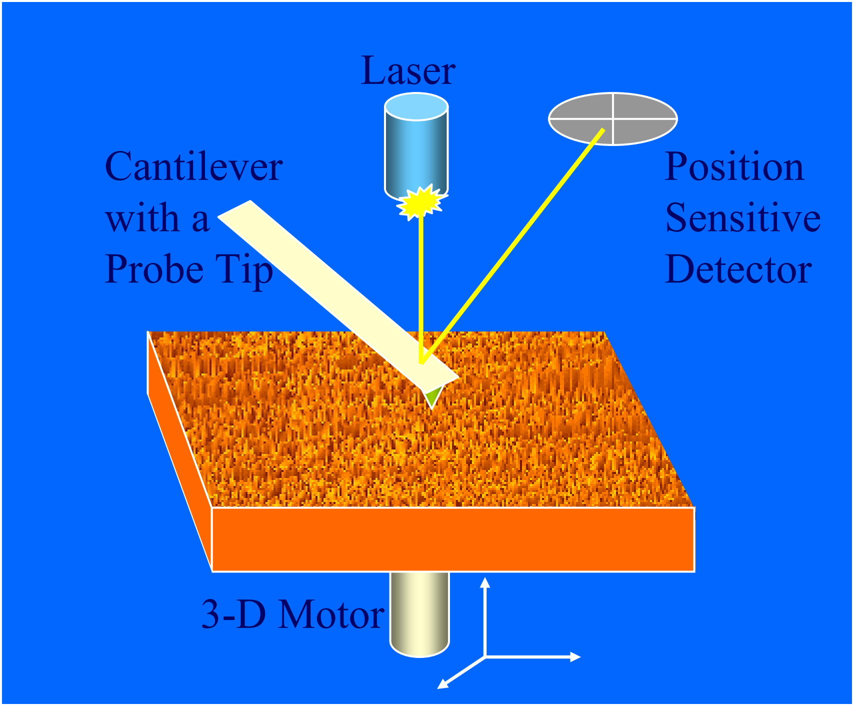
Computer Simulation and AFM characterization of irradiated Si PIN

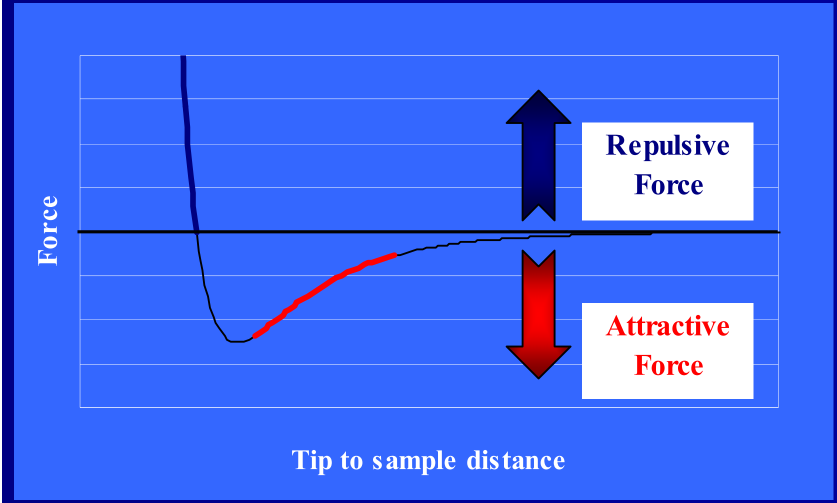
Arie Ruzin, I. Torchinski
School of EE, Tel Aviv University, Israel

OUTLINE

- Atomic Force Microscopy methods
- Experimental results with new and irradiated PIN structures
- Trap dominated semiconductors: is there type inversion ?
- Computer simulation of “double junction” with recent trap data
- Summary (?)

Atomic Force Microscope





AFM – Topography Measurement

Taping Mode

- The cantilever is vibrated far from the sample and the amplitude dependence of frequency is monitored by PSD

- The cantilever vibrated near the resonance frequency approaches the sample

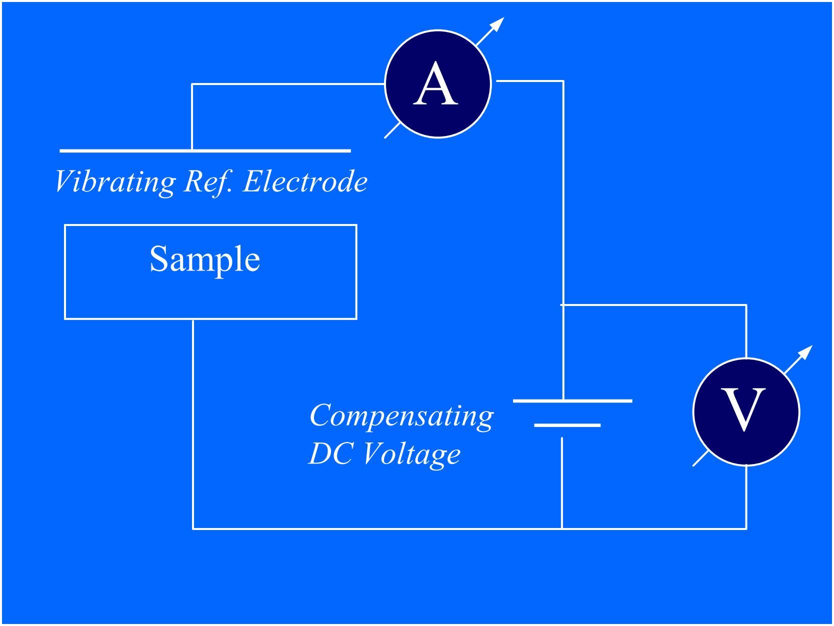
- The tip comes close to the surface (a few nm) starts sensing Van der Waals force, which changes the vibration amplitude

- The vibration amplitude is monitored by PSD

- The PSD Feedback signal controls the sample to tip distance by a piezo motor

Atomic Force Microscope : Surface Potential Difference – SPD or Contact Potential Difference - CPD

$$-qV_{SPD}=\phi_{Tip}-\phi_{SC}$$



SPD measurement

Lift Mode for SPD

- Four passes are made over each line: two in taping mode, and two in lift mode

- During the taping passes the topography data is recorded

- During the Lift Mode® passes the tip is lifted by typically 50-100nm above the sample (using topography information)

- ac (ω_0) potential is applied between the tip and the sample

- DC bias is added by feedback circuit to the ac potential to eliminate cantilever vibrations at ω_0

SPD measurement

The force between the tip and the sample is:

$$F = -\frac{dU}{dz} = -\frac{1}{2}\frac{dC}{dz}V^2 = -\frac{1}{2}\frac{dC}{dz}\left\{\left(V_{DC} + V_{SPD}\right) + V_A \sin(\omega_0 t)\right\}^2 =$$

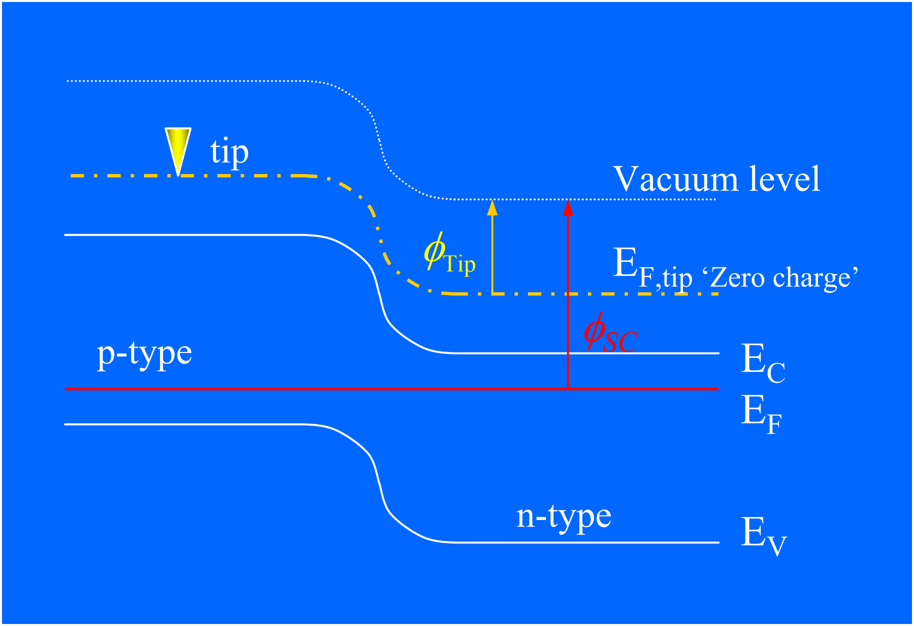
$$= -\frac{1}{2}\frac{dC}{dz}\left\{\left(V_{DC} + V_{SPD}\right)^2 + 2\left(V_{DC} + V_{SPD}\right)V_A \sin(\omega_0 t) + V_A^2 \sin^2(\omega_0 t)\right\}^2 =$$

$$= -\frac{1}{2}\frac{dC}{dz}\left\{\left[\left(V_{DC} + V_{SPD}\right)^2 + \frac{V_A^2}{2}\right] + 2\left(V_{DC} + V_{SPD}\right) \times V_A \sin(\omega_0 t) - \left(\frac{V_A^2 \cos(2\omega_0 t)}{2}\right)\right\}$$

The cantilever is elastic and will response to the force. The vibration mode at frequency ω_0 will become zero when $V_{DC}=-V_{SPD}$.

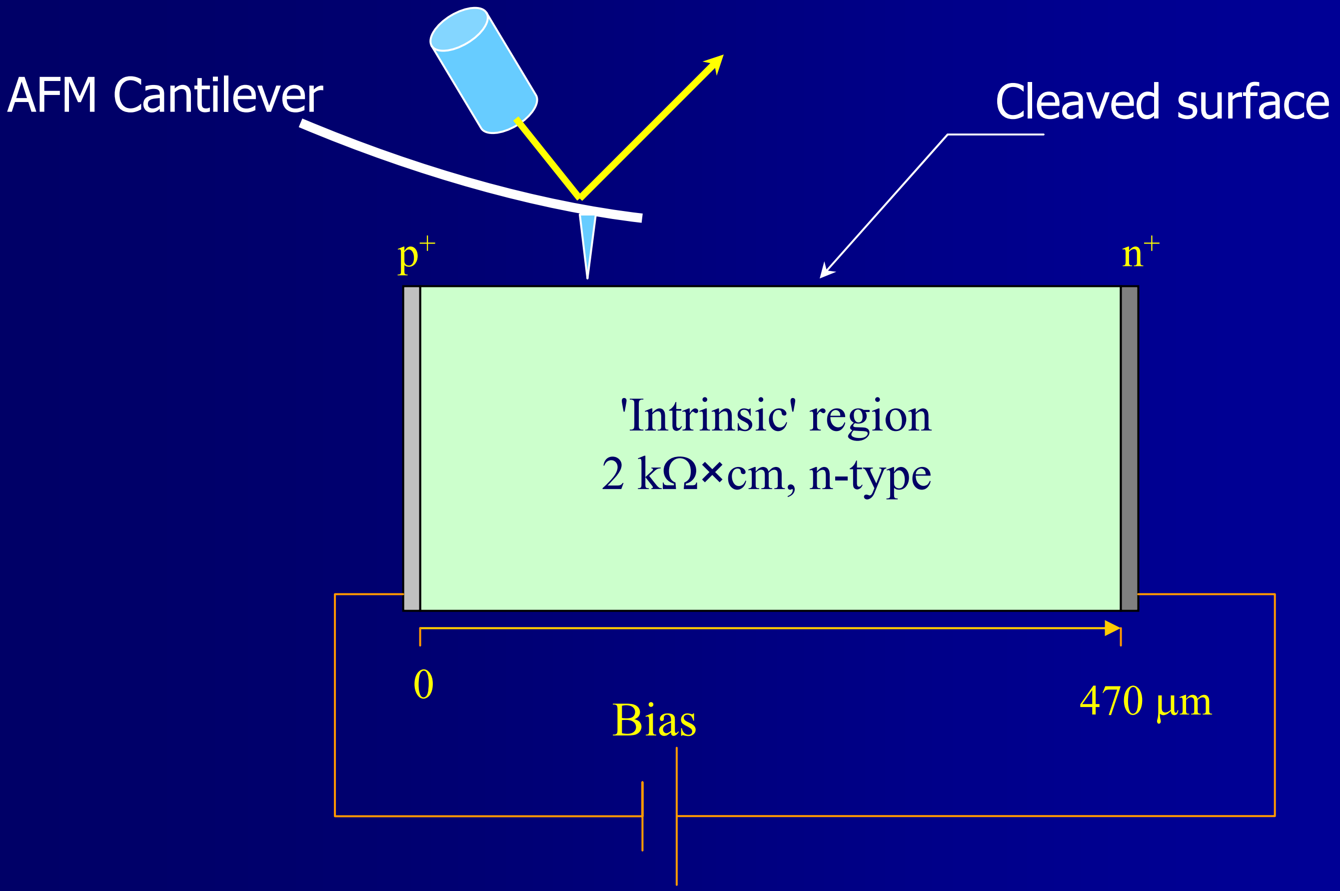
Atomic Force Microscope : Surface Potential Difference - SPD

$$-qV_{SPD} = \phi_{Tip} - \phi_{SC}$$

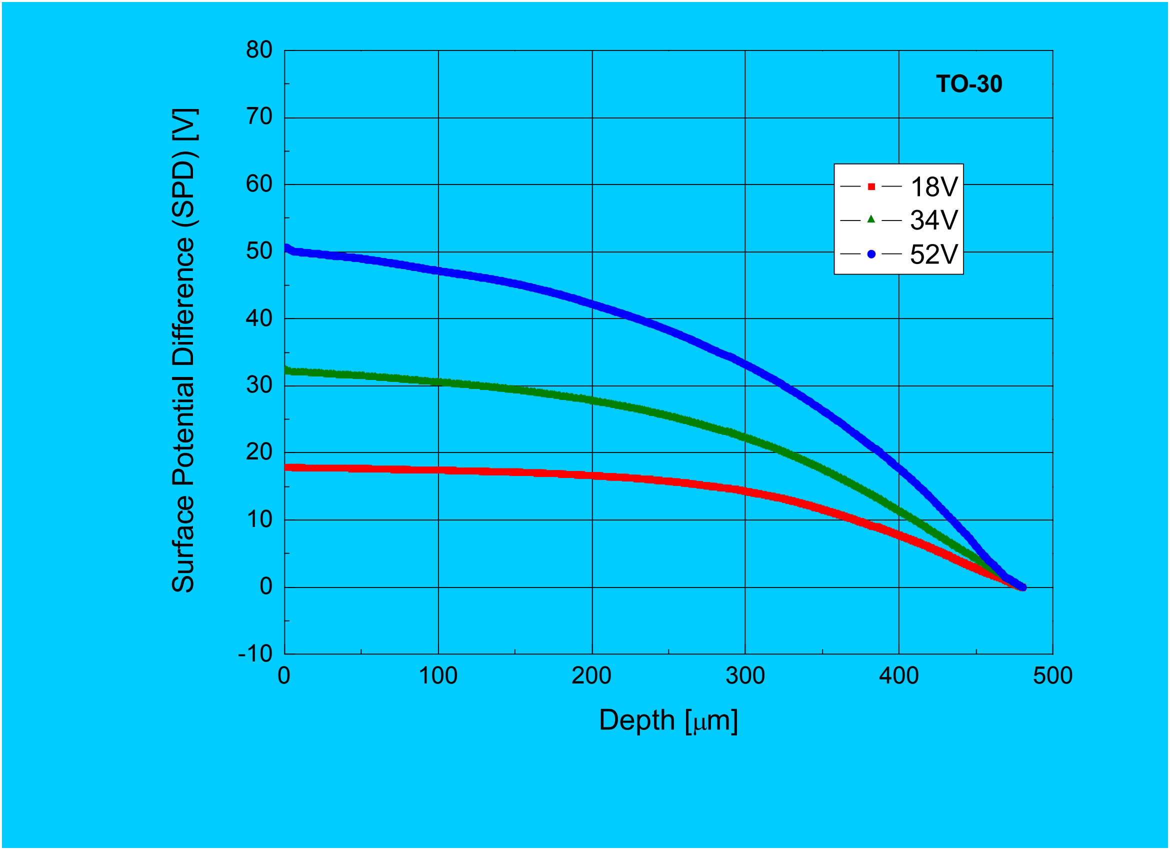


Atomic Force Microscope

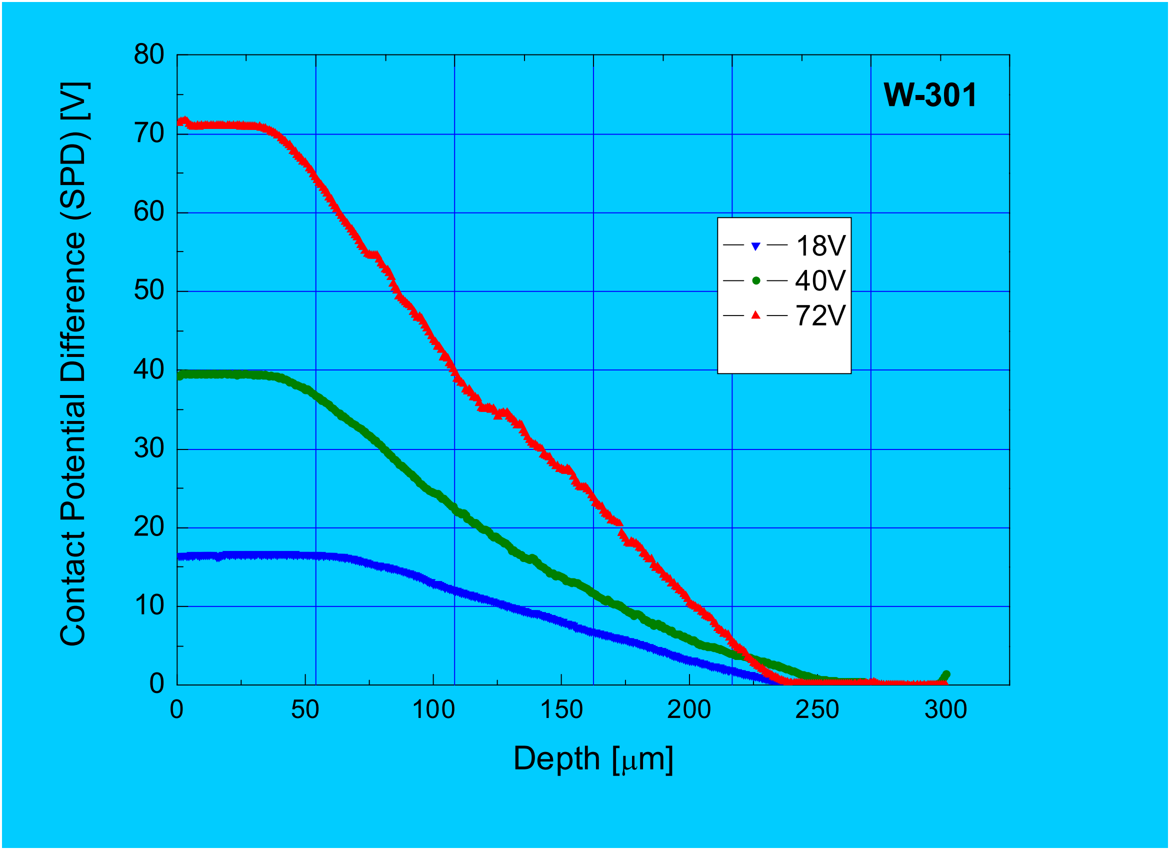
Device under test



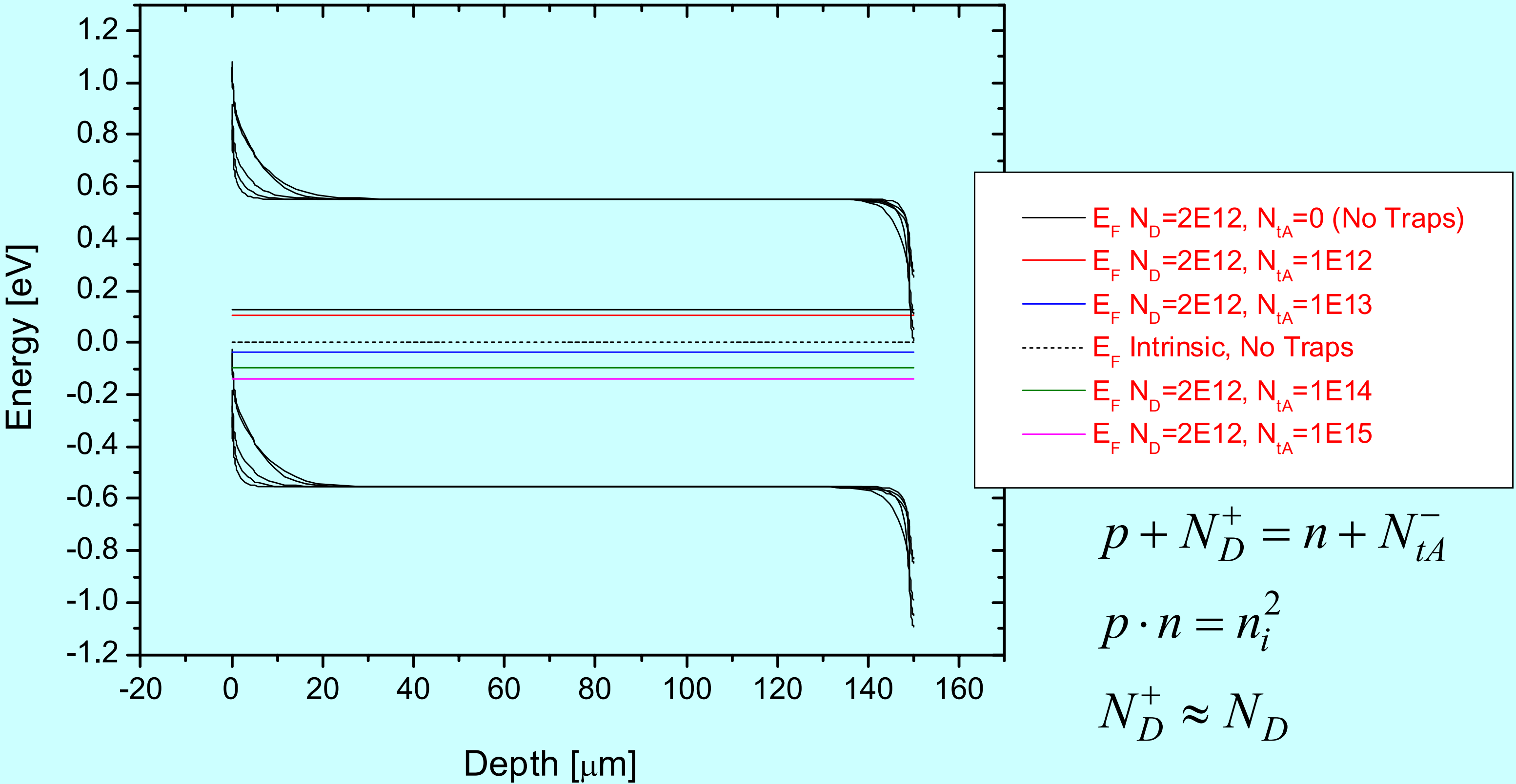
SPD measurement
Non-Irradiated device



SPD measurement
Irradiated device



Effect of Deep Acceptors in n-type Si

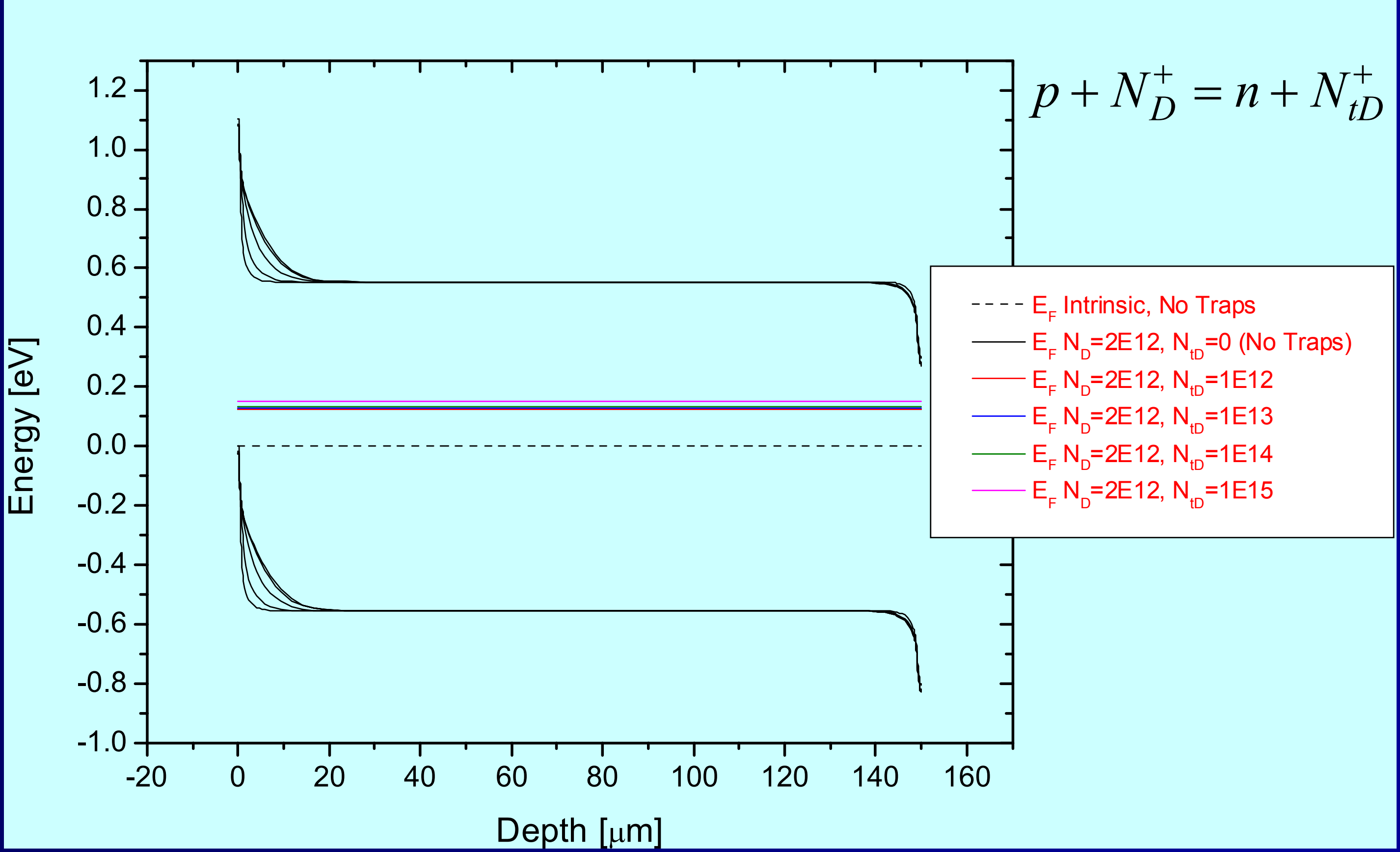


$$p + N_D^+ = n + N_{tA}^-$$

$$p \cdot n = n_i^2$$

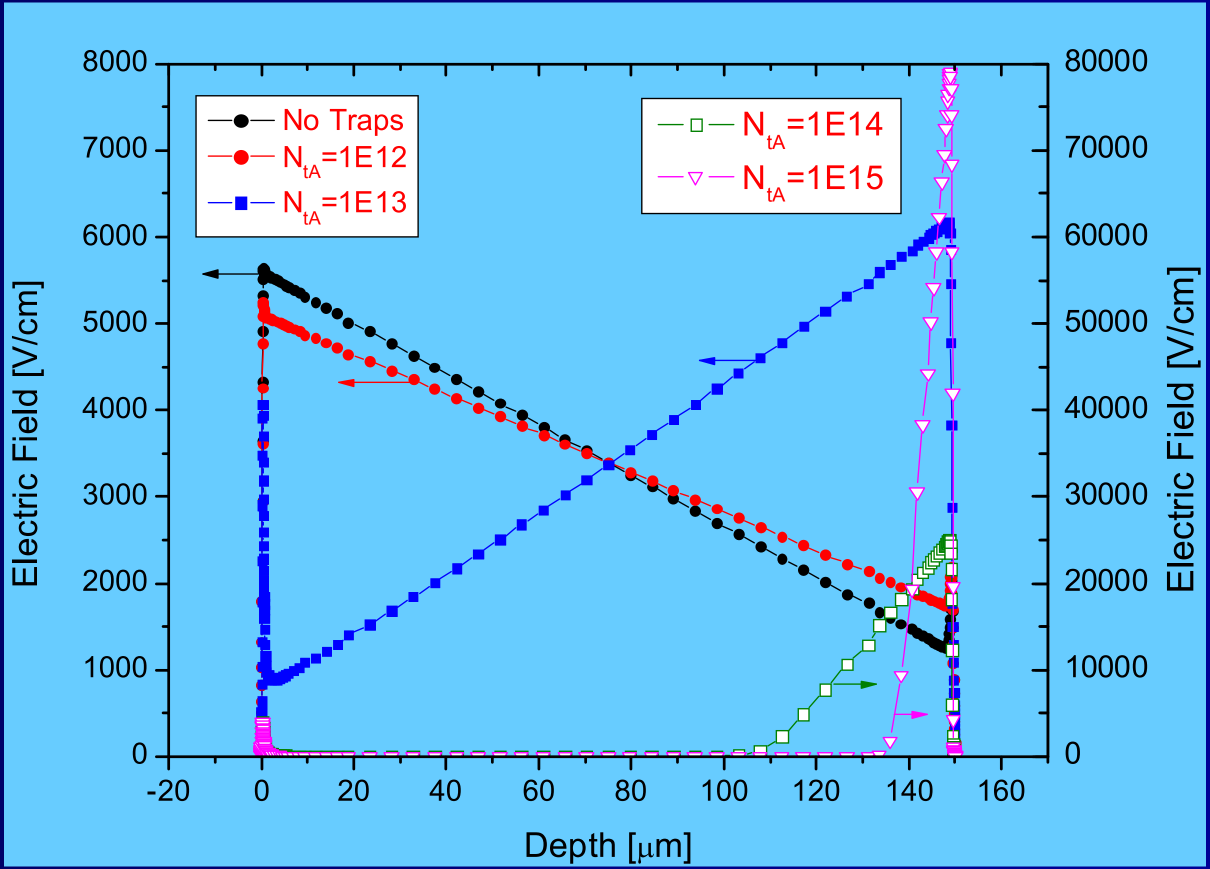
$$N_D^+ \approx N_D$$

Effect of Deep Donors in n-type Si

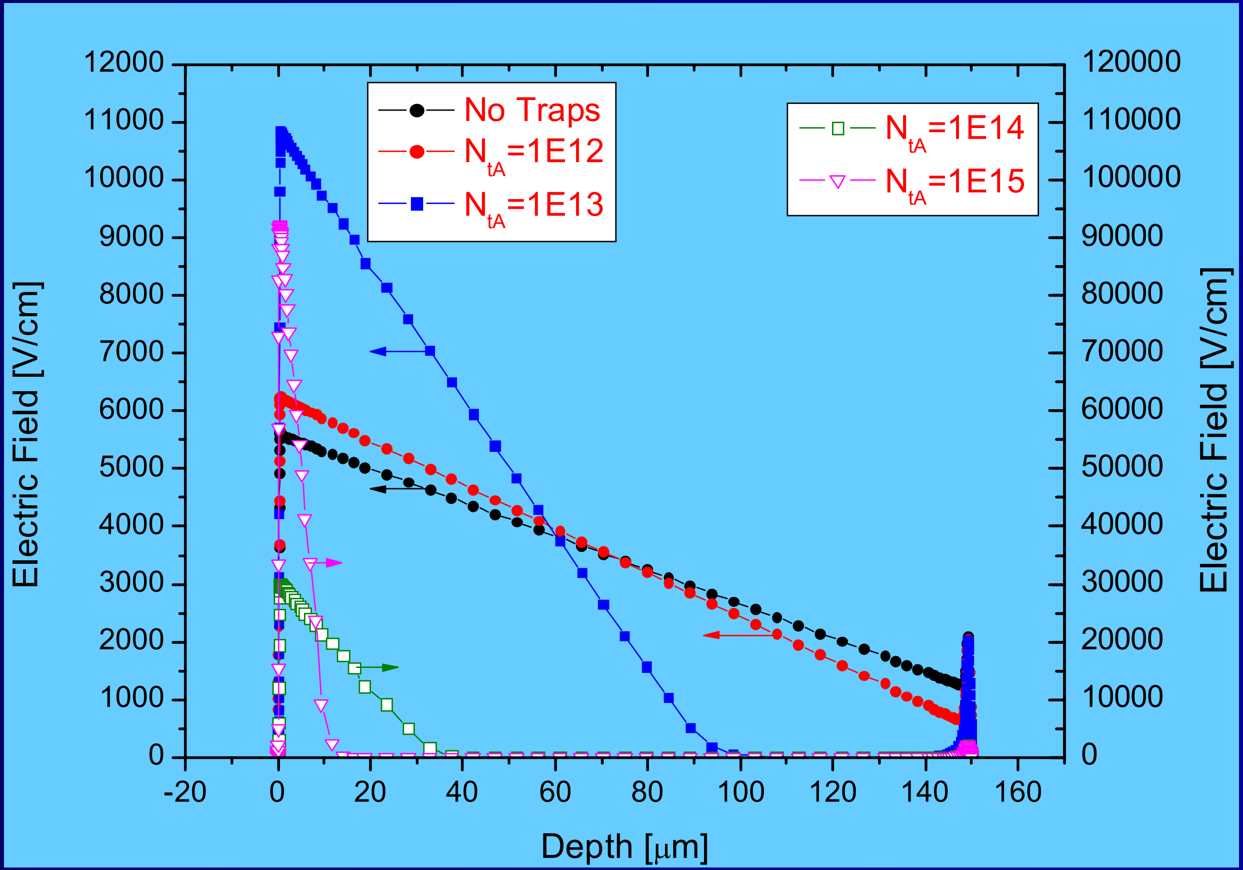


$$p + N_D^+ = n + N_{tD}^+$$

E-field variations in n-type Si due to deep “acceptors” <u>at midgap</u>



E-field variations in n-type Si due to deep “donors” <u>at midgap</u>



Candidates for deep “donors” and “acceptors”

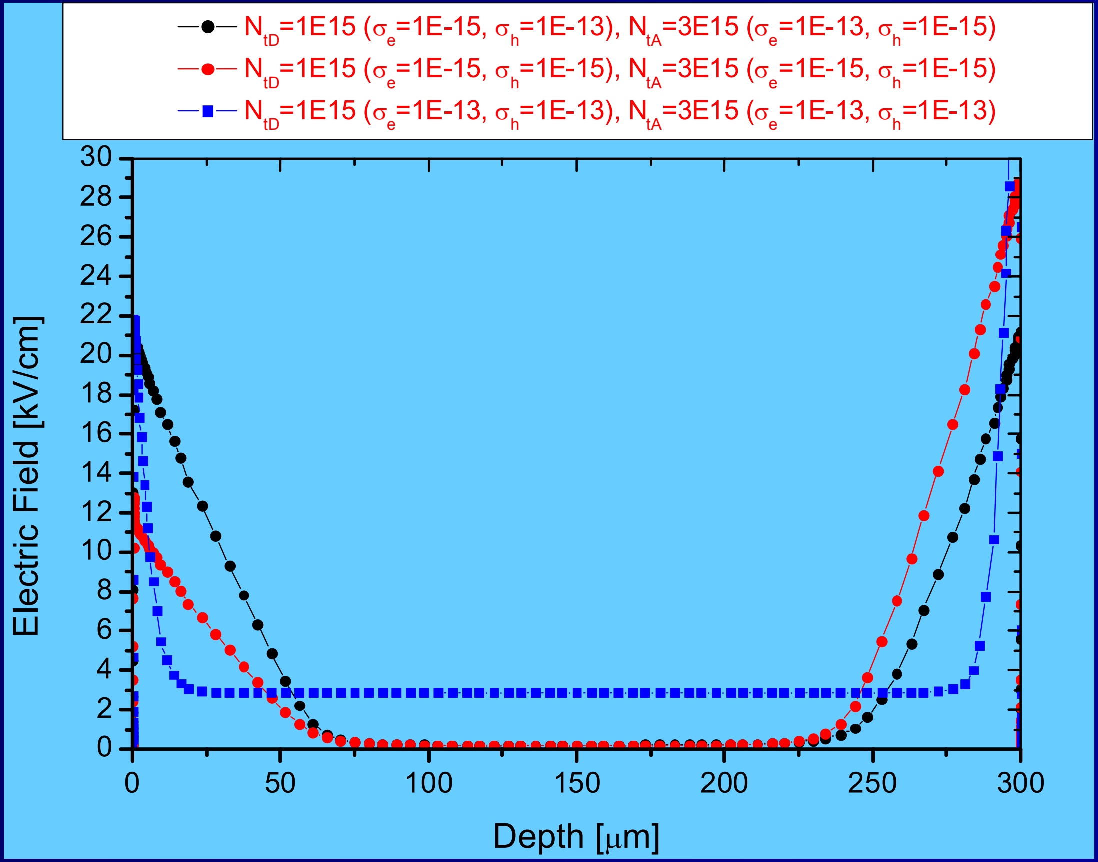
E(147)[1]	E_t=-0.37eV, σ_n=2.2×10^{-15}	Γ(240)[3]	E_t=0.68, σ_p=~5 >> σ_n *DA*
H(147) [1]	E_t=-0.363, σ_n=2.45,	H(97)[4,3]	E_t=0.23, σ_p=~0.5 DD?
E(158) [1]	E_t=-0.393, σ_n=1.3,	E(50)	DA?
H(165) [1]	E_t=0.4, σ_n=1.5,	BD(98)	DD, E_t=-0.15
E(168) [1]	E_t=-0.42, σ_n=2.1,	H(42)	
H(173) [1]	E_t=0.437, σ_n=2. 5,	H(47)	
E(174) [1]	E_t=-0.456, σ_n=5,	E(3)[5]	E_t=-0.17, σ_n=0.1
E(186) [1]	E_t=-0.48, σ_n=4,	E(6) [5]	E_t=-0.42, σ_n=2
I(200)[4]	E_t=-0.58, σ_n=1.7, σ_p=0.9, DA , γ	H(1) [5]	E_t=0.36, σ_p=2

1. I. Pintilie, et at., NIM A476 (2002), p. 652-657
2. I. Pintilie, et at., APL 81, No 1 (2002), p. 165
3. I. Pintilie, et at., APL in press
4. I. Pintilie, APL 82, No 13, 2003, p. 2169
5. E. Fretwurst, et al., NIM A377, (1996), p. 258

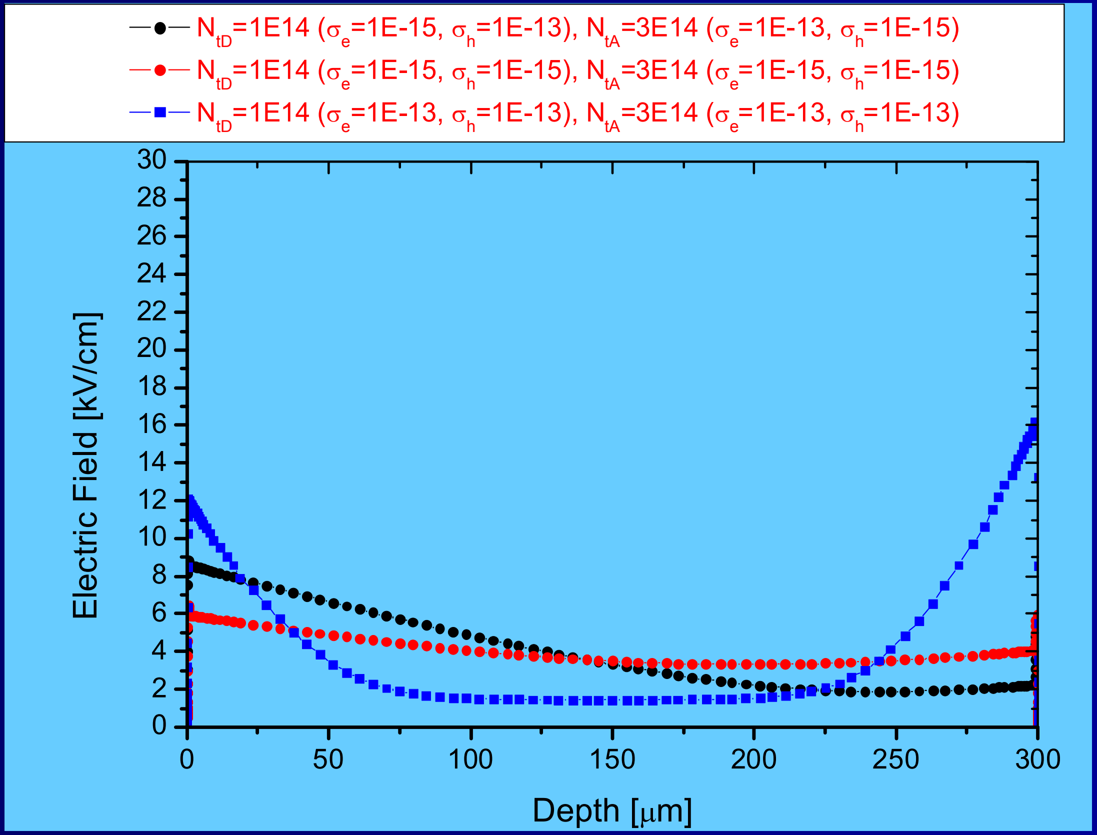
E-field variations in n-type Si due to Deep Acceptors +Donors

E_{tD}=0.53eV

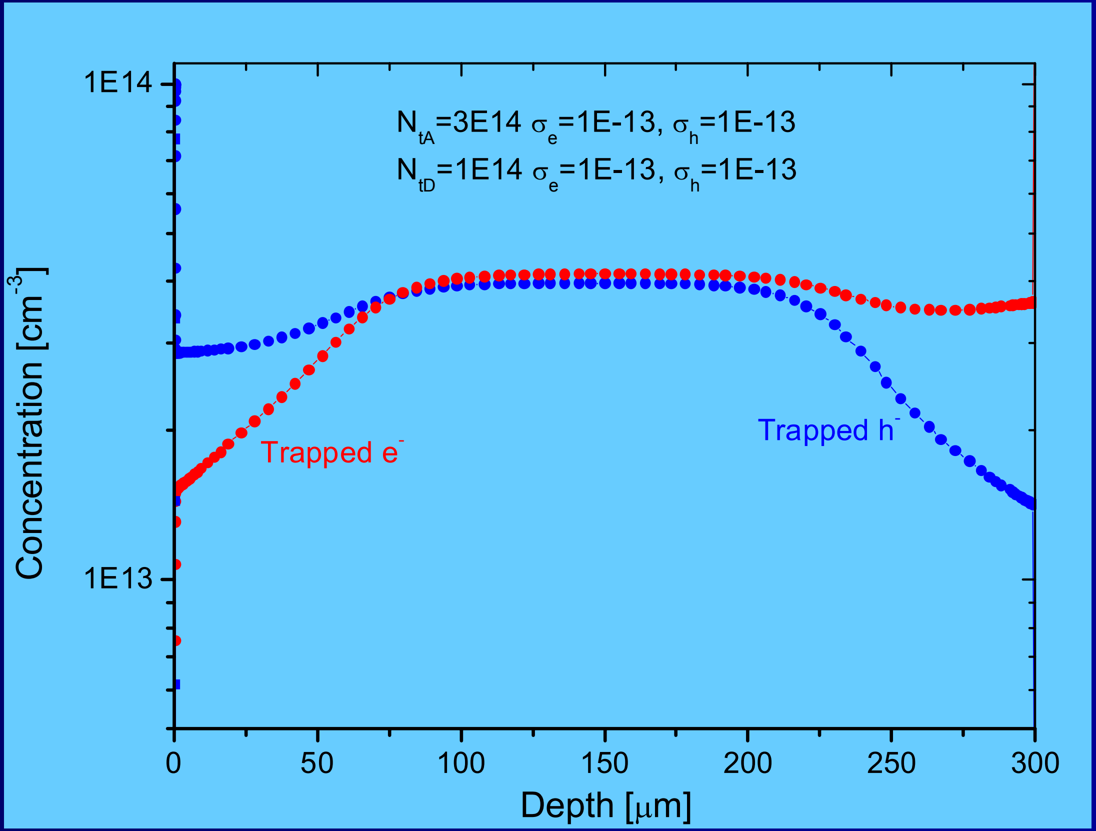
E_{tA}=0.52eV



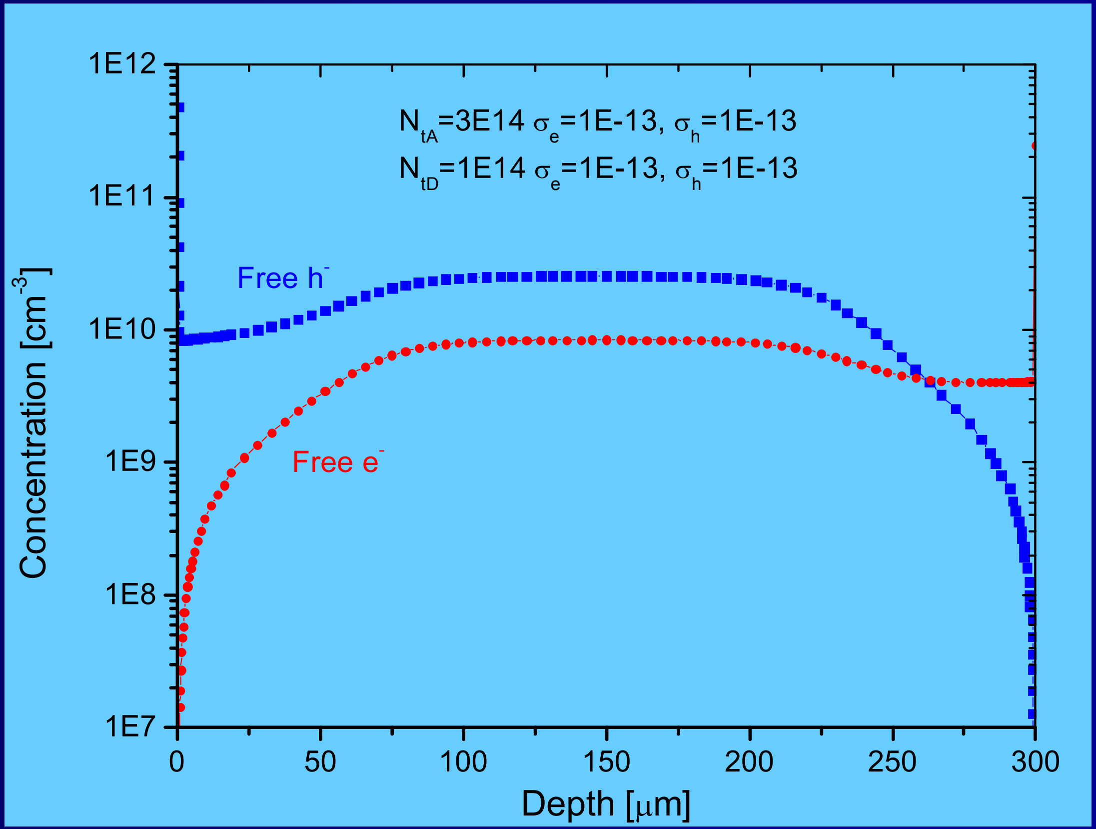
E-field variations in n-type Si due to Deep Acceptors +Donors



Trapped Carriers in n-type Si due to Deep Acceptors + Donors

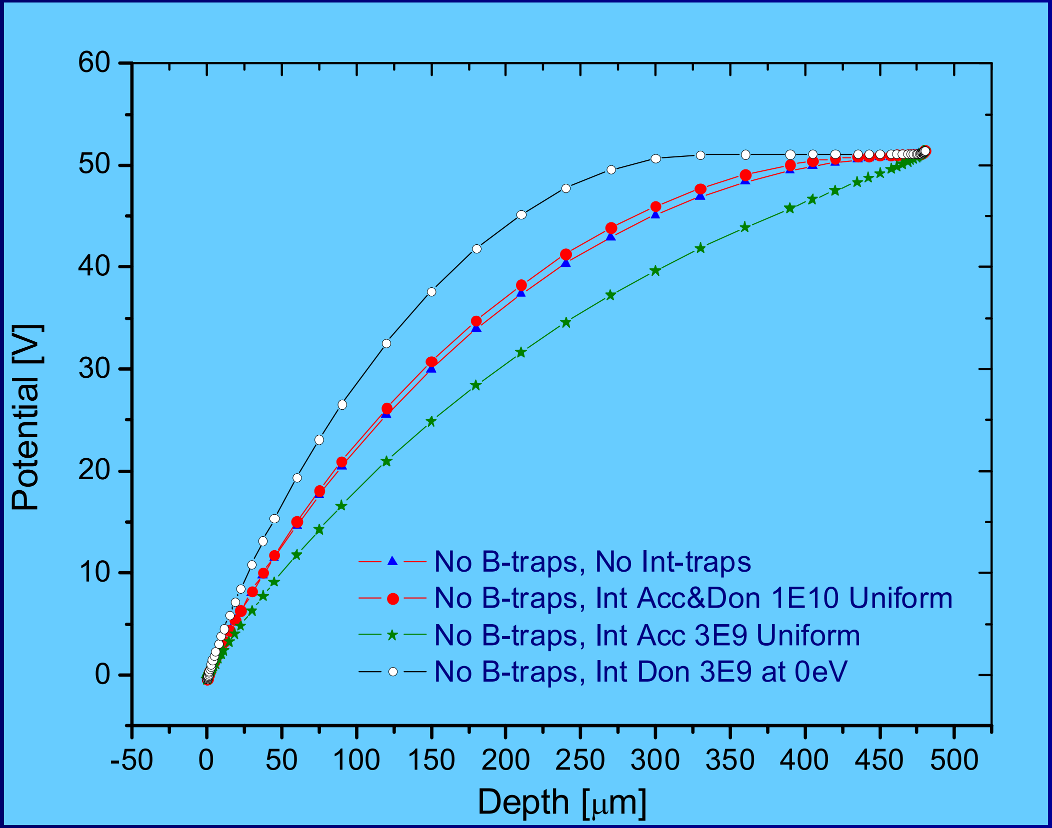


Free Carriers in n-type Si due to Deep Acceptors + Donors



Cleaved Surface Sensitivity to Interface Traps

Computer Simulation



Cleaved Surface Sensitivity to Interface Traps

Computer Simulation