p*-n-n* diode CV characteristics changes at various contact and body doping concentrations. *TCAD simulation*

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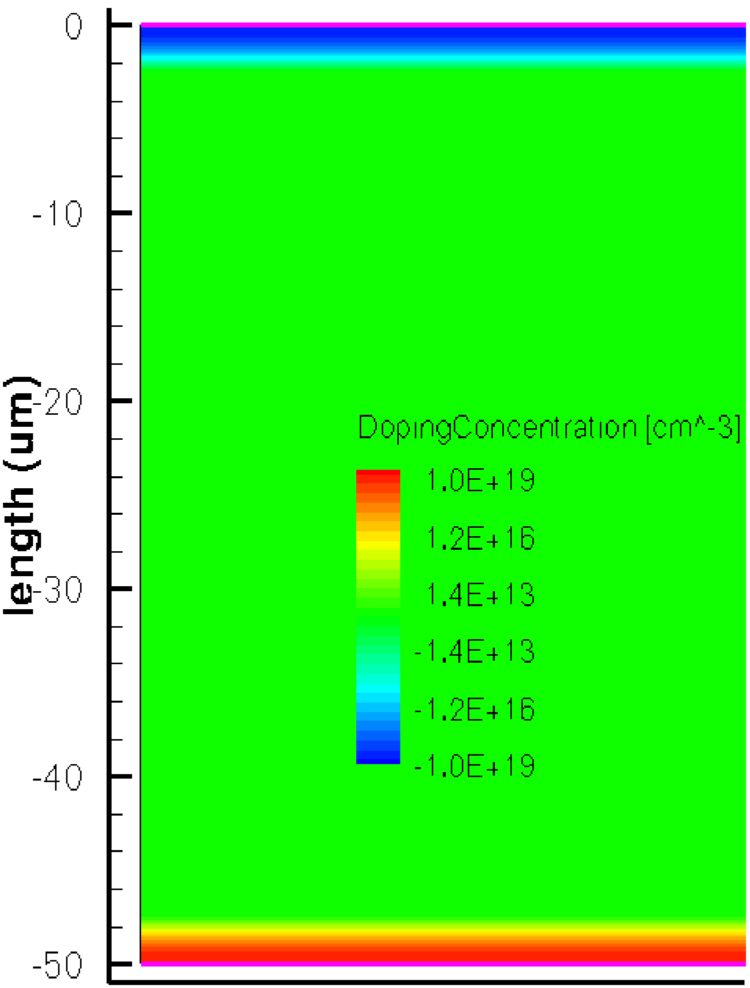
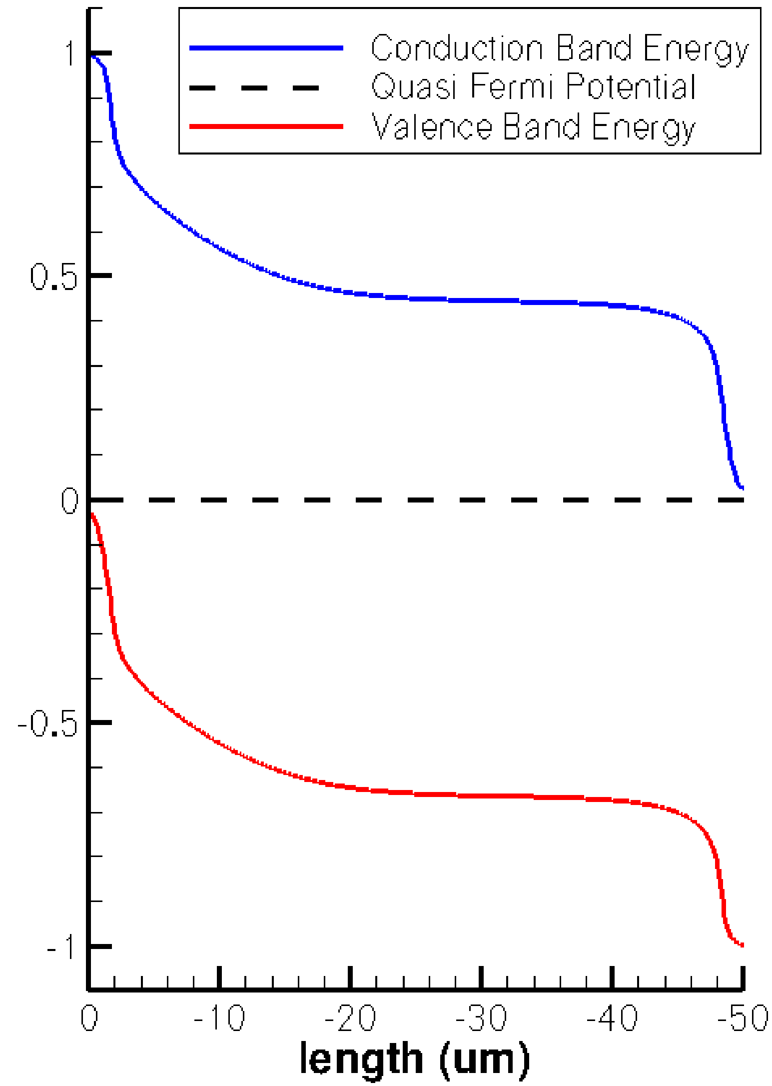
Device doping profile and energy band structure



contact doping:
p+ type,
1e17 – 1e20 cm^{-3}

body doping:
n-type
1e12 – 1e17 cm^{-3}

contact doping:
n+ type,
1e17 – 1e20 cm^{-3}



- This work is devoted to analyze the capacitance of *p*nn** structure if the *n* region is differently compensated.

- The role of doping in *n** and *p** regions is also analyzed. The TCAD Synopsys program was used for simulations.

- The modeled device is a two dimensional *p*nn** silicon based diode having *p** contact region with gaussian doping profile of 2 μm width and $N_p = 10^{19}$ *cm*$^{-3}$ *peak concentration. The n region homogeneous doping concentration* N_d *was variated within* $10^{12} – 10^{17}$ *cm*$^{-3}$*.*

- *The n* contact region doping profile was of gaussian type of variable 220 microns width and variable* $10^{13} – 10^{20}$ *cm*$^{-3}$ *peak concentration* N^+*. The device length L along direction perpendicular to junction planes was 50 and 300 μm and its width W along the perpendicular dimension was chosen 600 μm.*

- *Sentaurus TCAD output results for the 2D device are presented as for the 3D device of 1 μm height. The mesh along length direction was 1000-4000 points and only 3 points along width direction. Such a mesh efectively models one dimensional device.*

Model equations (following Synopsys TCAD manual)

Poisson

$$\nabla \cdot (\varepsilon \nabla \phi + \vec{P}) = -q(p - n + N_{\mathrm{D}} - N_{\mathrm{A}}) - \rho_{\mathrm{trap}}$$

Continuity equations

$$\nabla \cdot \vec{J}_n = qR_{\mathrm{net}} + q\frac{\partial n}{\partial t} \qquad -\nabla \cdot \vec{J}_p = qR_{\mathrm{net}} + q\frac{\partial p}{\partial t}$$

Carrier transport (hydrodynamic model)

$$\vec{J}_n = q\mu_n\left(n\nabla E_{\mathrm{C}} + kT_n\nabla n - nkT_n\nabla \ln\gamma_n + \lambda_n f_n^{\mathrm{td}} kn\nabla T_n - 1.5nkT_n\nabla \ln m_n\right)$$

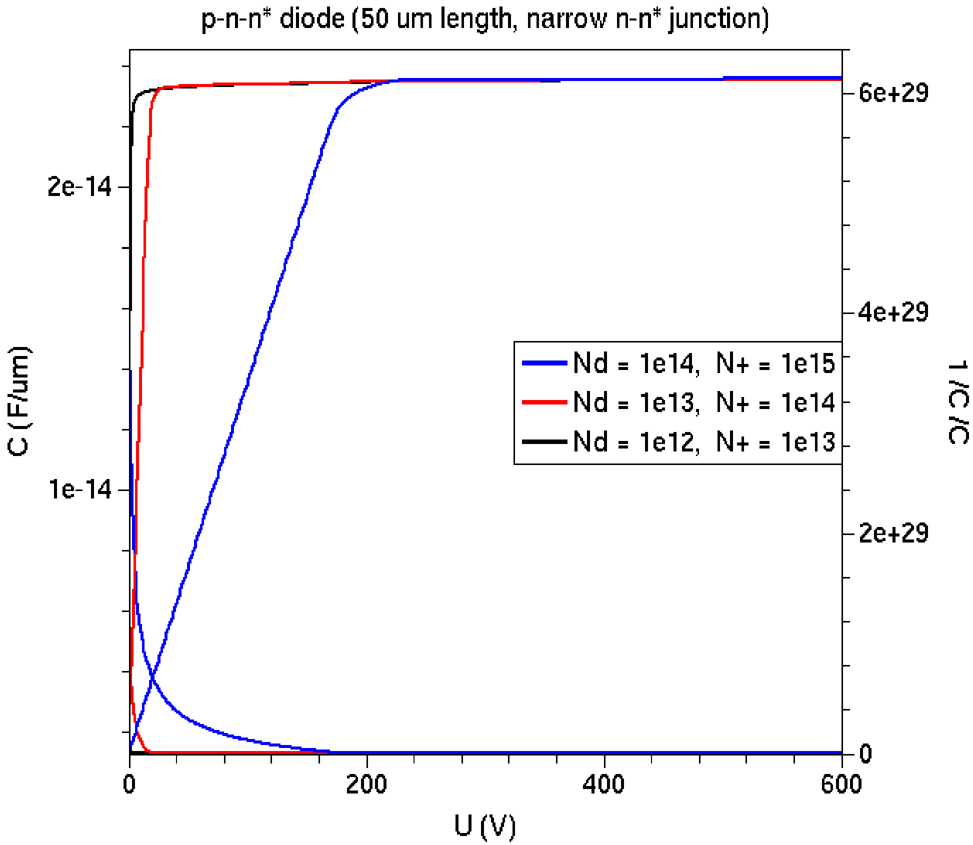
$$\vec{J}_p = q\mu_p\left(p\nabla E_{\mathrm{V}} - kT_p\nabla p + pkT_p\nabla \ln\gamma_p - \lambda_p f_p^{\mathrm{td}} kp\nabla T_p - 1.5pkT_p\nabla \ln m_p\right)$$

Fermi statistics for band electrons and holes

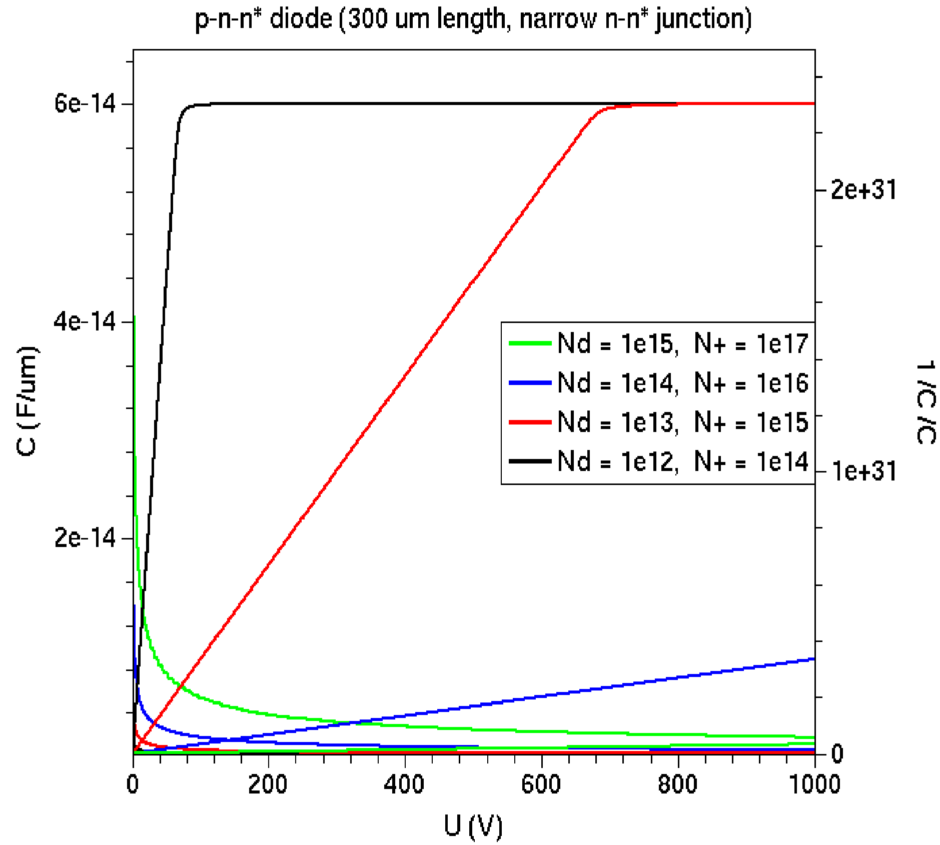
$$n = N_{\mathrm{C}} F_{1/2}\left(\frac{E_{\mathrm{F},n} - E_{\mathrm{C}}}{kT}\right) \qquad p = N_{\mathrm{V}} F_{1/2}\left(\frac{E_{\mathrm{V}} - E_{\mathrm{F},p}}{kT}\right)$$

Shokley-Read-Hall recombination, doping dependent mobility were not specified.

The CV characteristics were modeled at different donor doping concentrations and doping profiles of p*n and nn* junctions. Changing of donors concentrations in n and n* regions of the device effectively models its irradiation with a fluence of high energy particles of variable intensity, as long as the defects induced by these particles are mainly the types of acceptor traps which localize electrons thus reducing their concentration as a result of compensation.



L_{diode} = 50 um

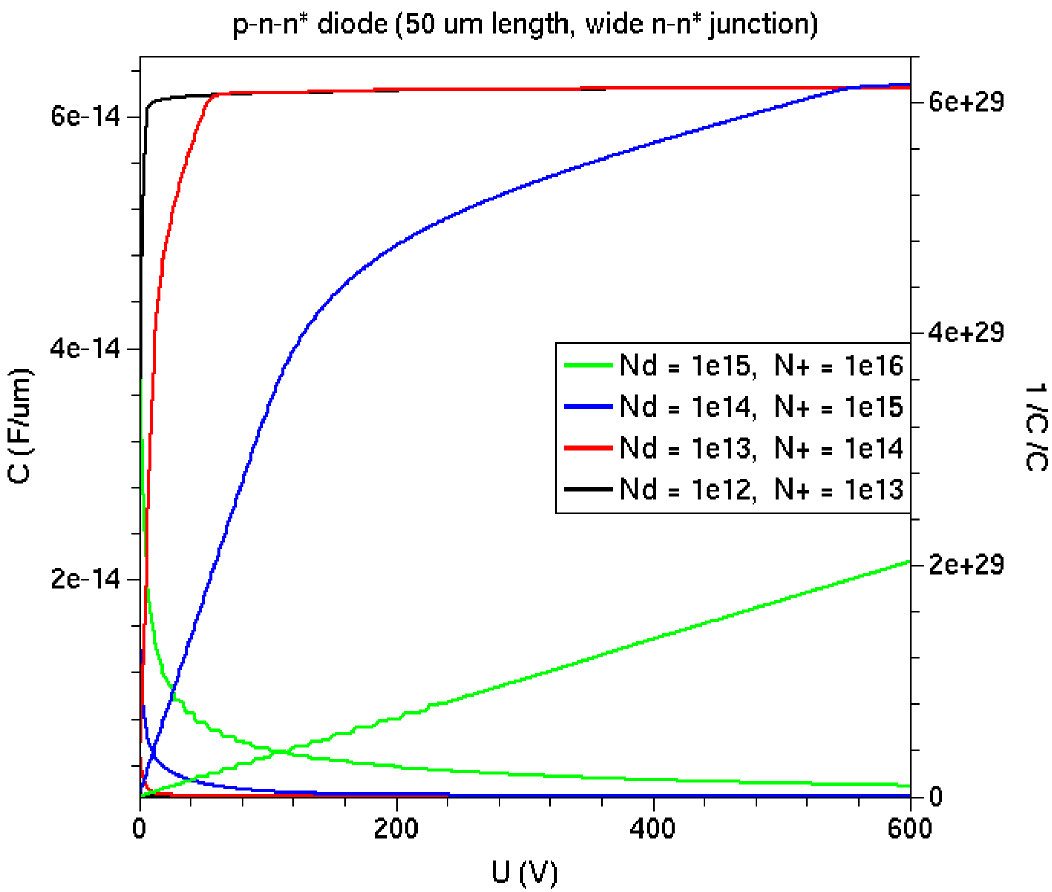


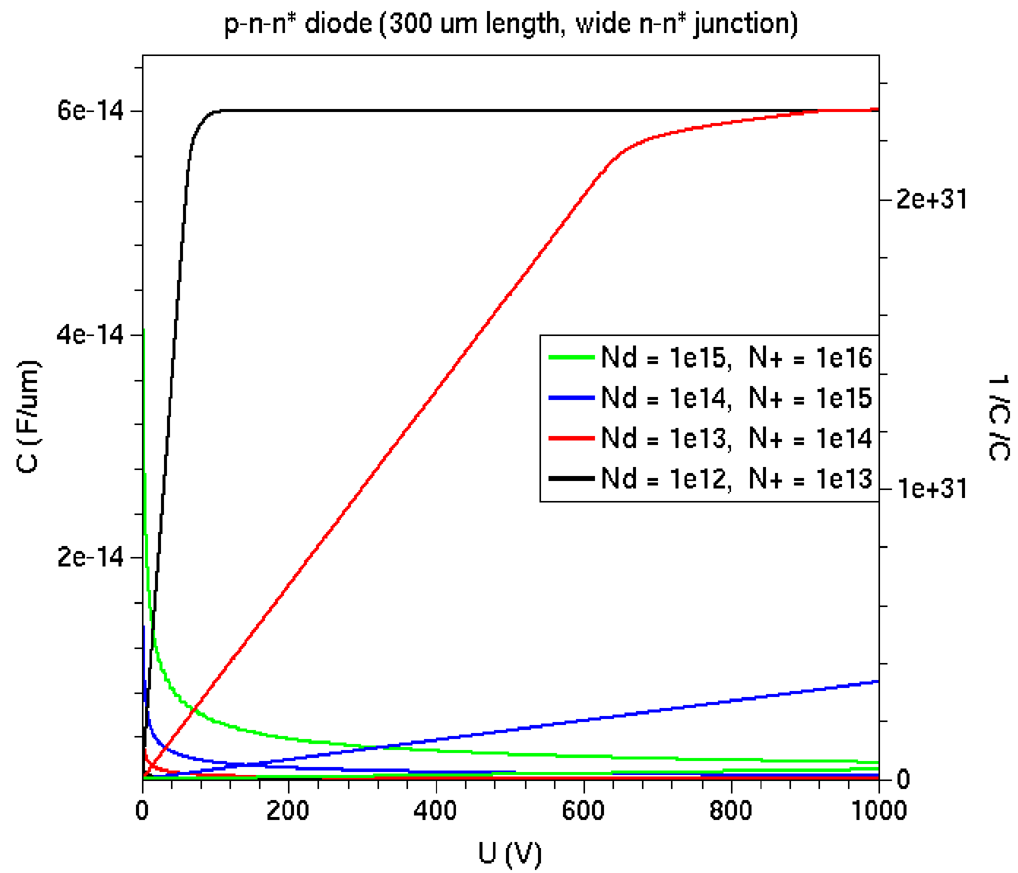
L_{diode} = 300 um

CV characteristics for the diode with ***narrow (2 microns) n* contact region***

Characteristics are shown for several values of n base doping concentration (Nd) and n peak concentration*

In some cases ((b) panel, blue and green curves) depletion is not reached at reasonable experimental values
depletion is possible only theoretically.





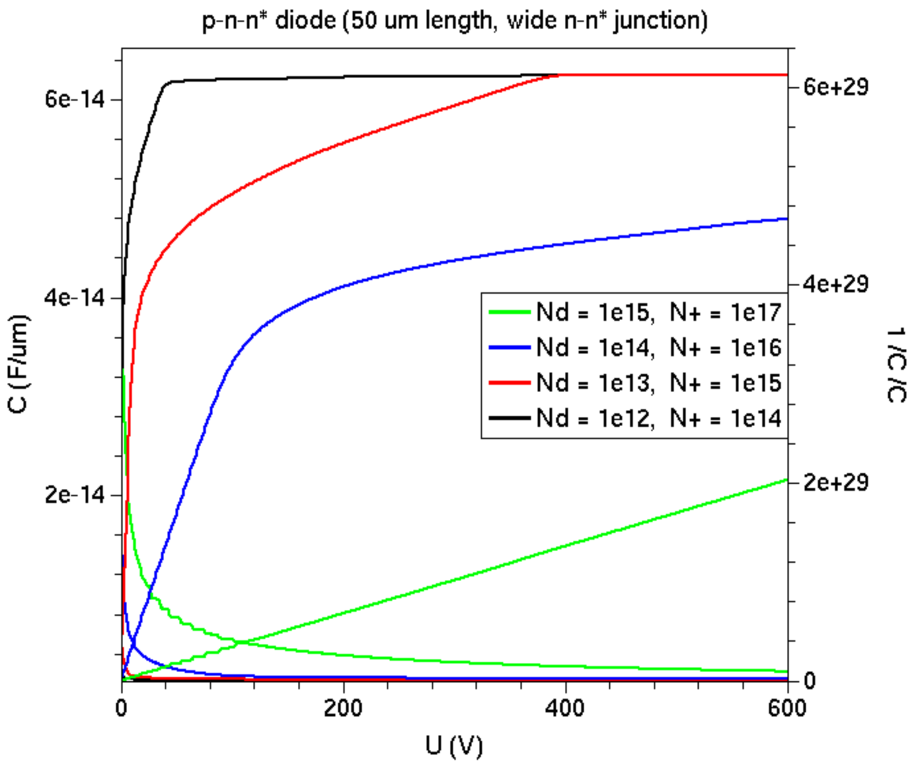
L_{diode} = 50 um

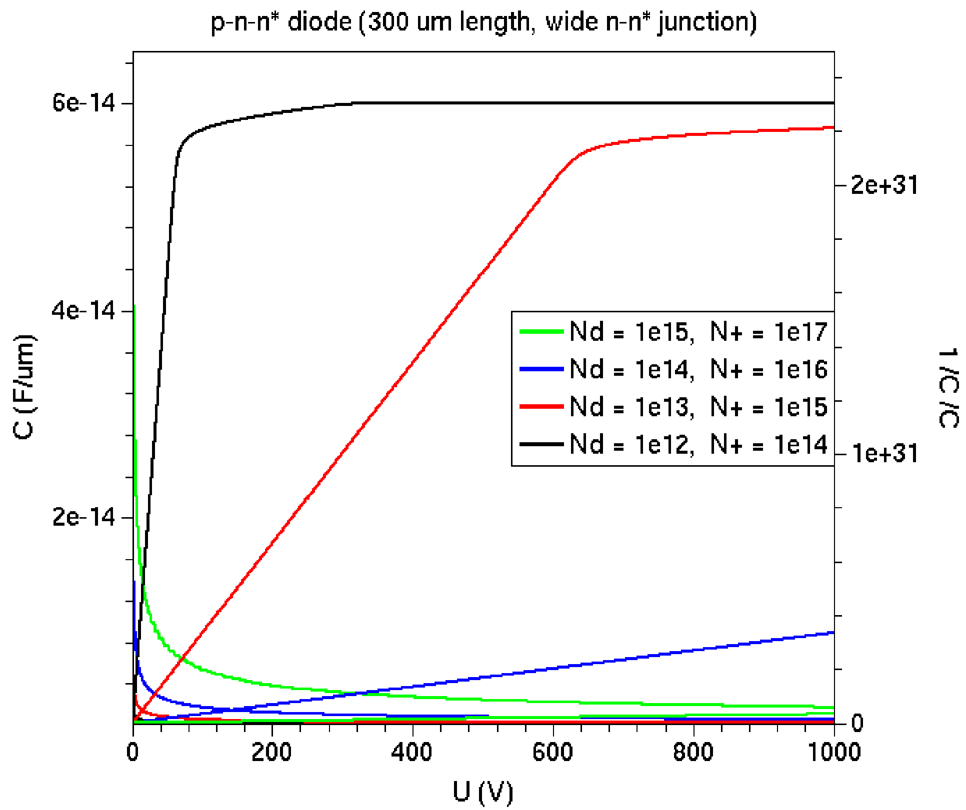
L_{diode} = 300 um

CV characteristics for the diode with ***wide (20 microns) n* contact region***

Characteristics are shown for several values of n base doping concentration (Nd) and n peak concentration (N+). The ratio of concentrations is* $\boldsymbol{N_+ / N_d = 10}$

When n contact region is wide some $1/C^2$ -V curves have two kinks signaling about two separate inputs to depletion effect from two junctions p-n and n-n**



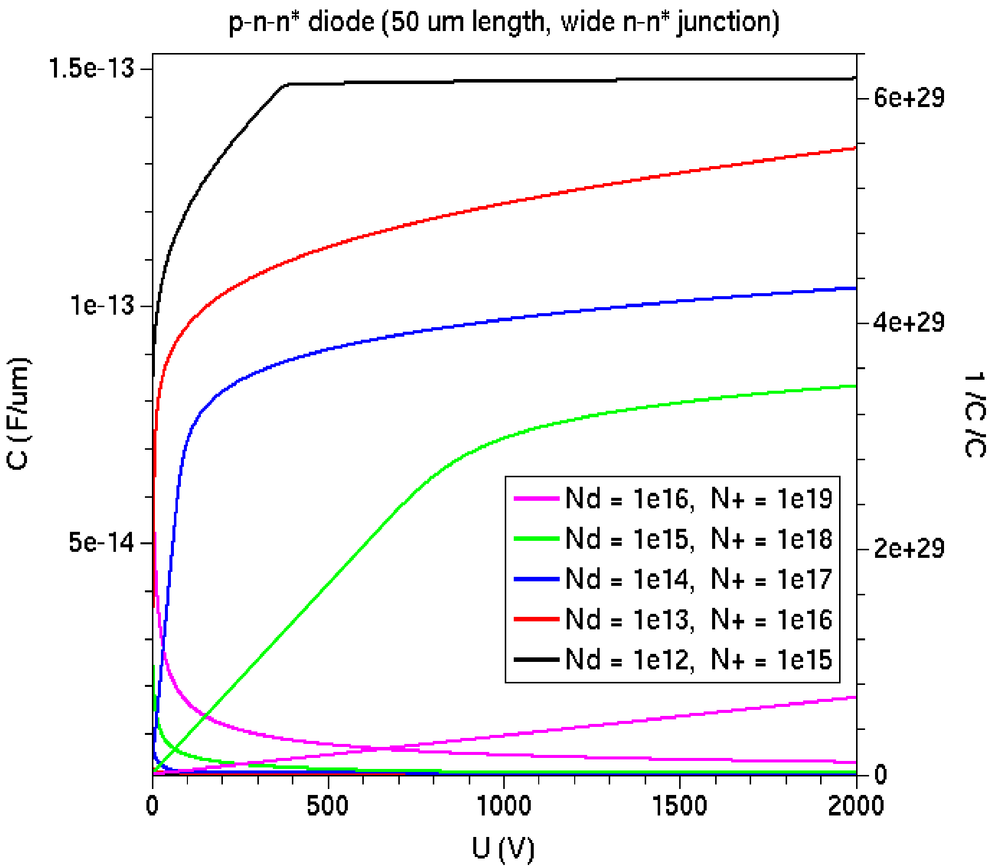


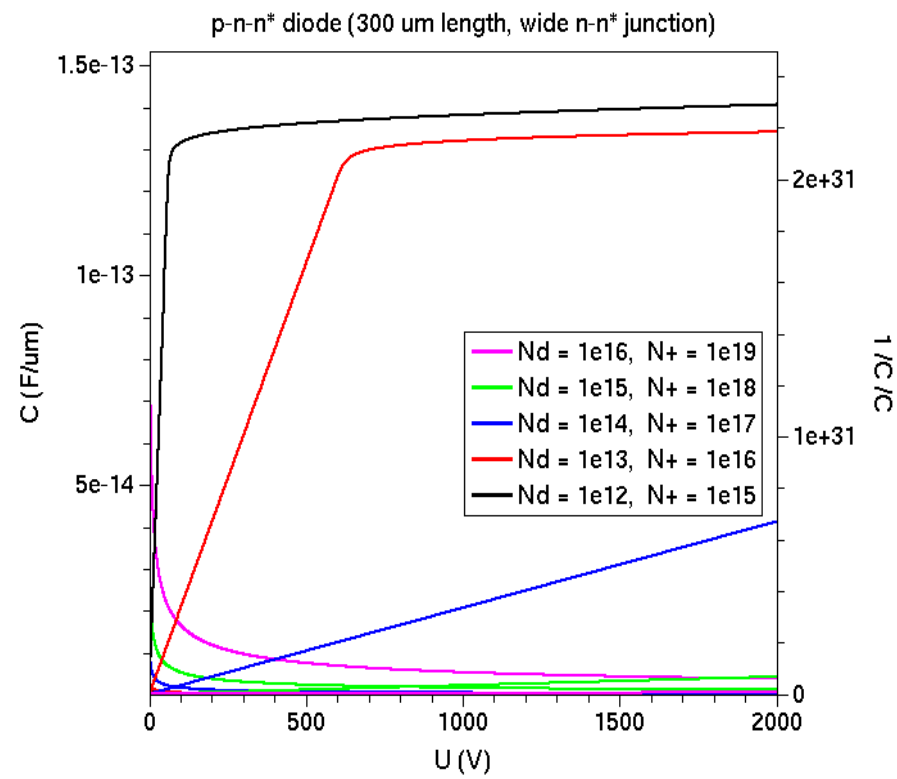
L_{diode} = 50 um

L_{diode} = 300 um

(Similar to previous slide but ***N_+ / N_d = 100*** *)*
CV characteristics for the diode with ***wide (20 microns) n* contact region***

Characteristics are shown for several values of n base doping concentration (Nd) and n peak concentration (N+). The ratio of concentrations is* ***N_+ / N_d = 100***
When n contact region is wide some $1/C^2$ -V curves have two kinks signaling about two separate inputs to depletion effect from two junctions p-n and n-n**





L_{diode} = 50 um

L_{diode} = 300 um

(Similar to previous slide but ***N_+ / N_d = 1000*** *)*

CV characteristics for the diode with ***wide (20 microns) n* contact region***

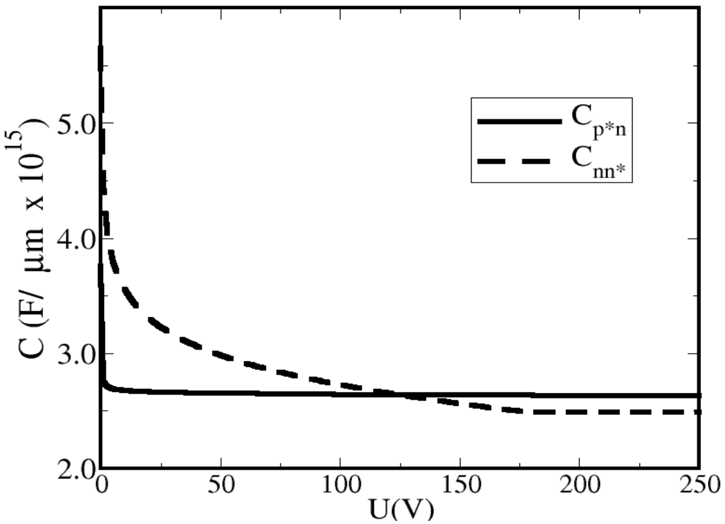
Characteristics are shown for several values of n base doping concentration (Nd) and n peak concentration (N+). The ratio of concentrations is* ***N_+ / N_d = 1000***

When n contact region is wide some $1/C^2$ -V curves have two kinks signaling about two separate inputs to depletion effect from two junctions p-n and n-n**

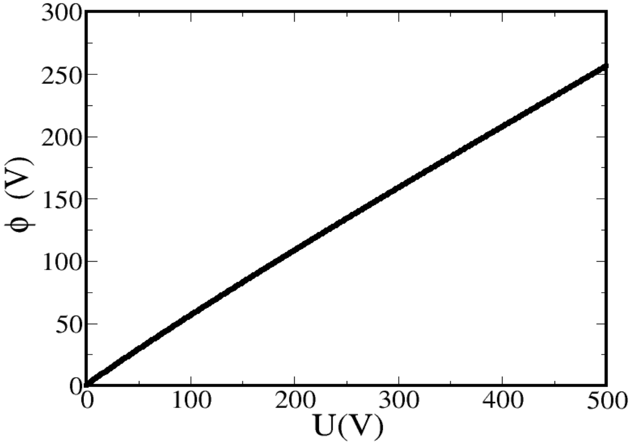
To explain the origin of the doubly kinked CV characteristic we suggest to present the p*nn* diode capacitance as a series of connected p*n and nn* capacitances.

To see if this is correct we have recorded the dependence of potential P_{hi} in the middle of p*nn* diode on the applied external voltage U.

p-n-n* diode modeled by two sequential junctions: p-n and n-n* (device length 50 um n* length 20 um $N_d = 10^{12} cm^{-3}$, $N_+ = 10^{15} cm^{-3}$)



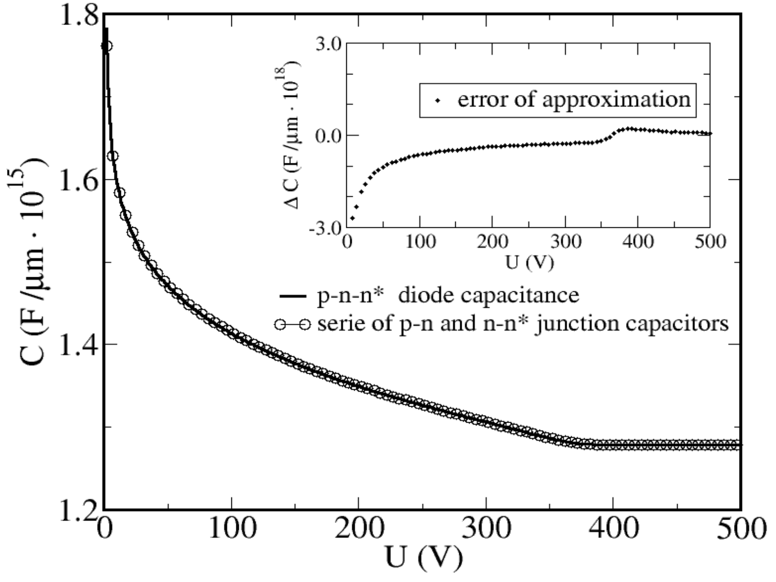
1) calculated C-V for two seperate p-n and n-n* junctions (each of half of the p-n-n* diode length)



2) during calculation of p-n-n* diiode C-V potential φ(V) dependence at the half of diode length is recorded

Then we have simulated the CV characteristic of p*n junction and nn* junction devices having the same doping profile as they were in p*nn* diode junctions but their length being only half of the diode length. Having obtained functions C(U) for both junctions one may present the resulting capacitance of diode as:

$$\frac{1}{C(U)} = \frac{1}{C_{pn}(\phi)} + \frac{1}{C_{nn*}(U-\phi)}$$



This formula was applied and the result (circles) was compared with p-n-n* diodes C-V (line)

Apart from perfect coincidence Figure 6 also demonstrates that the sharp kink in the CV (and *1/C2(V)*) occuring at U ~ 370 380 V originates itself from the *nn** junction capacitance which saturates at ~170 180 V. Exactly the same voltage (*U – phi*) falls on the half of diode with *nn** junction when the external voltage U = 370380 V is applied (see corresponding earlier figure).

Acknowledgements.

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Thank You for attention!