EE-612: Lecture 21:

On Becoming a True Technology Developer*

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(*some free advice)

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a true technology developer:

- Has a broad understanding of physics and chemistry, materials and devices, circuits, and systems.

- Understands theory, experiments, metrology and characterization, and design.

- Has a good feel for typical numbers.

- Can work on the ‘back of the envelope’ and fill in the details.

- Appreciates both the technology and business aspects.

- Knows how to use and ‘stand up to’ computer simulations.

about computer simulation

1) Modern engineering practice depends on computer simulations.
2) They are essential. They can, however, become a crutch, and they can get you in trouble - or they can make you a much better engineer.
3) All software has limitations and many contain errors. Get used to it.

one view of Spice

Many members of the Spice generation merely hack away at design. They guess at circuit values, run a simulation, and then guess at changes before they run the simulation again…..and again…..and again. Designers need an ability to create a simple and correct model to describe a complicated situation - designing on the back of an envelope. The back of the envelope has become the back of a cathode ray tube, and intuition has gone on vacation.

Paraphrased from:

Ronald A. Rohrer, "Taking Circuits Seriously," *IEEE Circuits and Devices*, July, 1990.

Don't become a Spice monkey!

on simulation programs

“All software begins with some fundamental assumptions that translate into fundamental limitations, but these are not always displayed prominently in advertisements. Indeed, some of the limitations may be equally unknown to the vendor and to the customer. Perhaps the most damaging limitation is that software can be misused or used inappropriately by an inexperienced or overconfident engineer.”

Henry Petroski, “Failed Promises,” *American Scientist*, **82**(1), 6-9 (1994)

on using simulation programs

"… a designer using such a program will have no easy way of discovering all the assumptions made by the programmer. Consequently, the designer must either accept on faith the program's results or check the results – experimentally, graphically, and numerically – in sufficient depth to satisfy himself that the programmer did not make dangerous assumptions or omit critical factors and that the program reflects fully the subtleties of the designer's own unique problem."

from *Engineering in the Mind's Eye*, by Eugene S. Fergusson

on analysts vs. designers

"Because structural analysis and detailing programs are complex, the profession as a whole will use programs written by a few. Those few will come from the ranks of structural "analysts" … and not from the structural "designers." Generally speaking, their design and construction-site experience and background will tend to be limited. It is difficult to envision a mechanism for ensuring that the products of such a person will display the experience and intuition of a competent designer… . More than ever before, the challenge to the profession and to educators is to develop designers who will be able to stand up to and reject or modify the results of a computer-aided analysis and design."

A Canadian structural engineer quoted by Eugene S. Fergusson in *Engineering in the Mind's Eye*, MIT Press (1993)

stand up to a computer!

“The engineers who can **stand up to a computer** will be those who understand that software incorporates may assumptions that cannot be easily detected by its users but which affect the validity of the results. There are a thousand points of doubt in every complex computer program. Successful computer-aided-design requires vigilance and the same visual knowledge and intuitive sense of fitness that successful designers have always depended upon when making critical design decisions.”

from:

Eugene S. Fergusson, *Engineering in the Mind’s Eye*, MIT Press (1993)

true technology developers

“The basic difference between an ordinary TCAD user and an true technology designer is that the former is relaxed, accepting on faith the program’s results, the latter is concerned and busy checking them in sufficient depth to satisfy himself that the software developer did not make dangerous assumptions. It takes years of training in good schools, followed by hands-on design practice to develop this capability. It cannot be acquired with short courses, or with miracle push-button simulation tools that absolve the engineer of understanding in detail what he is doing.”

Paraphrased from:

Constantin Bulucea, “Process and Device Simulation in the Era of Multi-Million-Transistor VLSI - A Technology Developer’s View,” IEEE Workshop on Simulation and Characterization, Mexico City, Sept. 7-8, 1998.

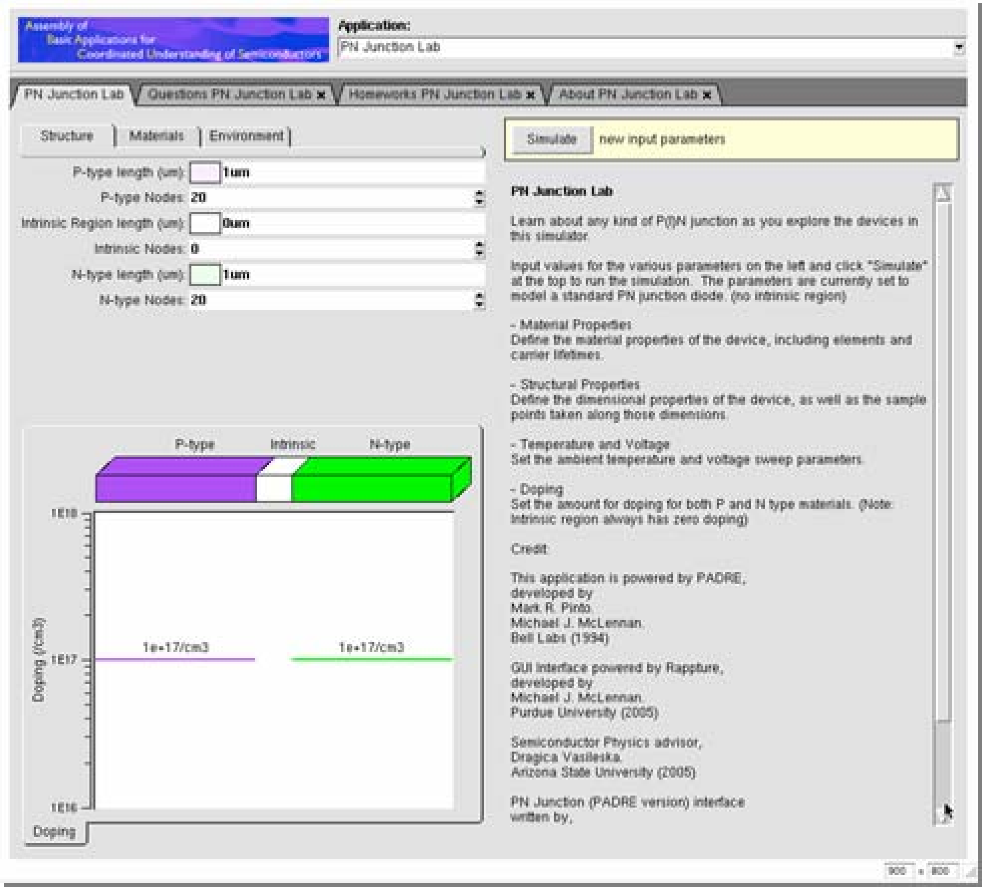
his computer “lied” to him

Bob Pease,
analog circuit designer
National Semiconductor

how to use a new simulation tool

- Understand what the tool does
  - -what equations are being solved?
  - -what numerical methods are used?
  - -what physical models are implemented?
- Try a simple problem first to be sure you get the correct answer
- Look for example files - close to the problem you're interested in.
- Know what the default settings are
- Ask an experienced user for help

PN Junction Lab



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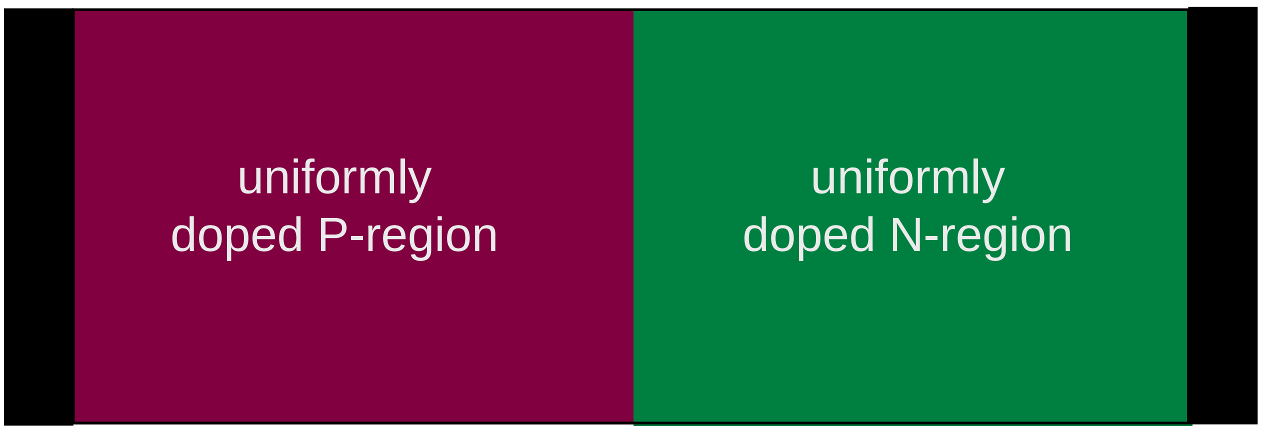
what problem does it solve?

ideal, ohmic contacts

abrupt junction

ideal, ohmic contacts



$n = n_0$

$p = p_0$

$n = n_0$

$p = p_0$

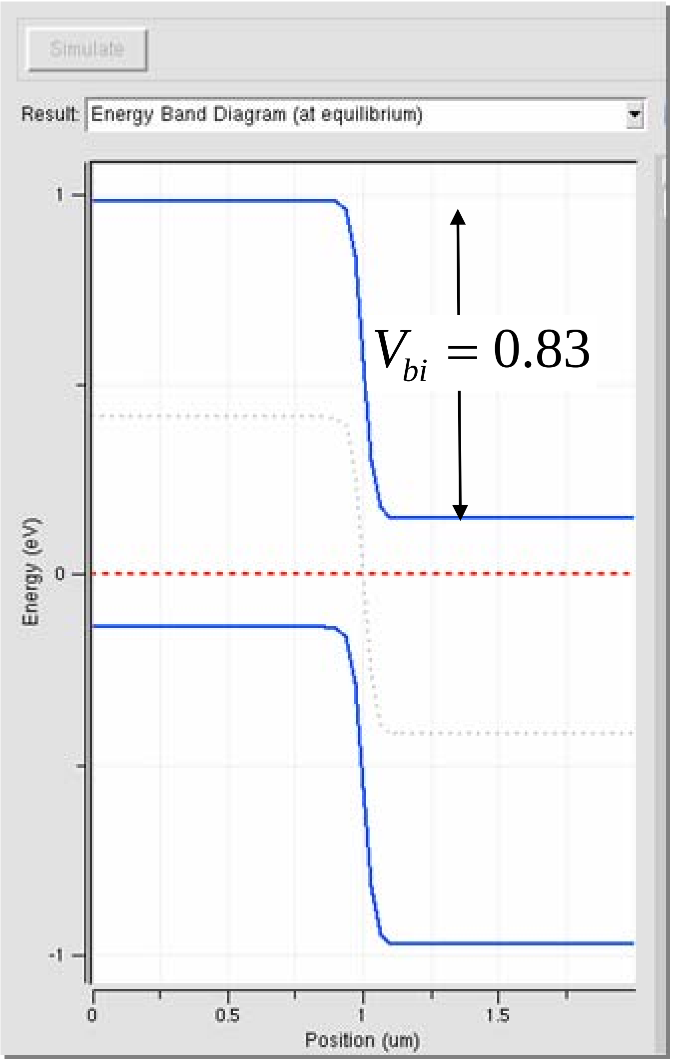
$R(n, p) = ?$

$\mu(N_{D,A}\vec{E}) = ?$

$$\frac{d^2V(x)}{dx^2} = q\left(p - n + N_D - N_A\right)$$

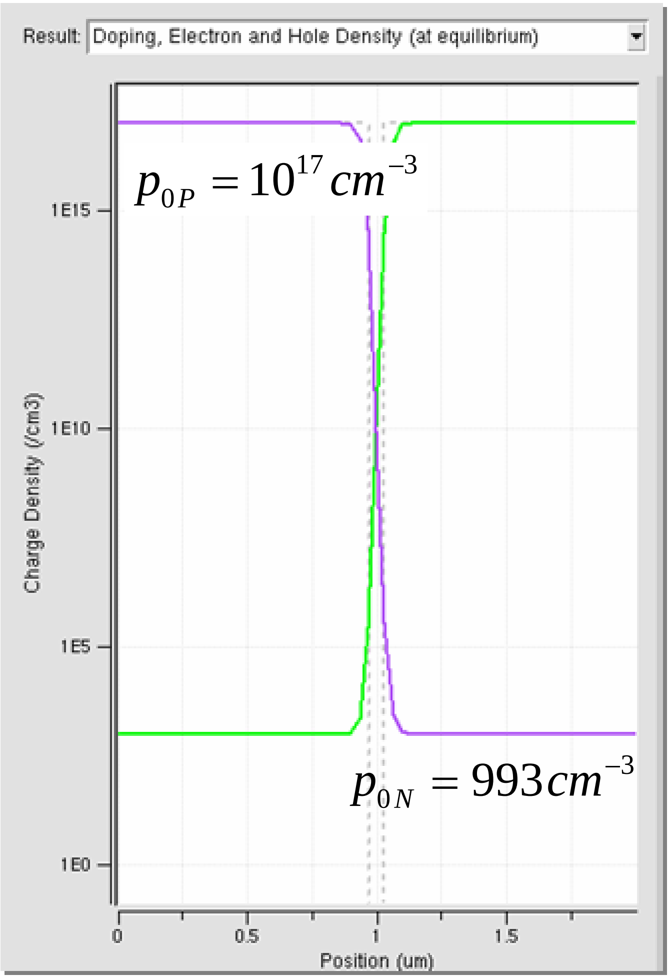
$$\frac{dJ_n}{dx} = q\left(R - G\right) \qquad \frac{dJ_p}{dx} = q\left(G - R\right)$$

default simulation



$$V_{bi} = \frac{k_B T}{q} \ln \frac{N_A N_D}{n_i^2} = 0.026 \ln 10^{10} = 0.84V$$

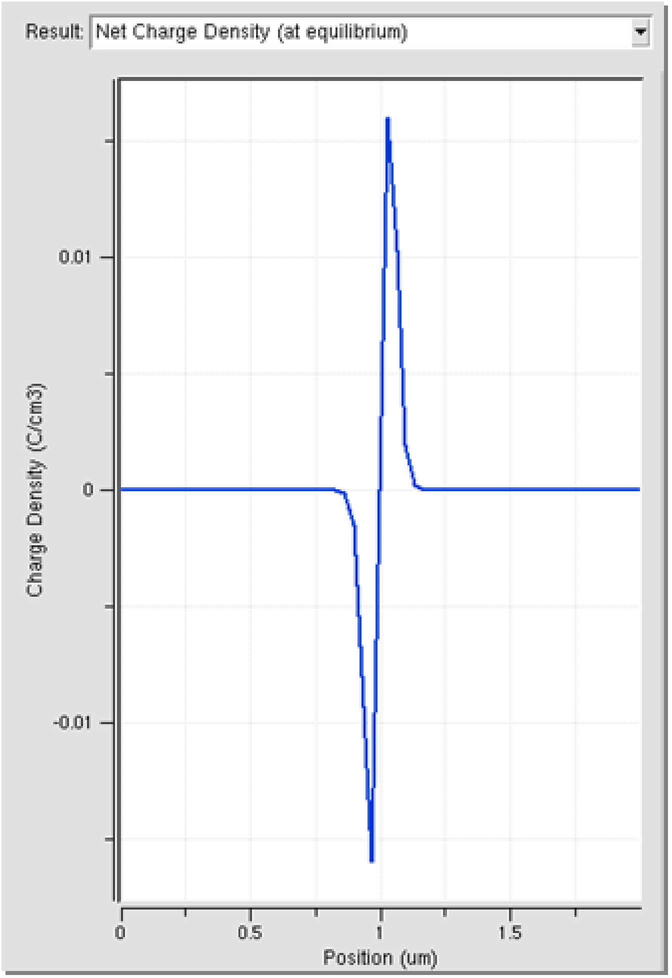
equilibrium carrier densities



$$p_{0P} \approx N_A = 10^{17}$$

$$p_{0N} \approx \frac{n_i^2}{N_D} = \frac{10^{20}}{10^{17}} = 1000$$

space charge density

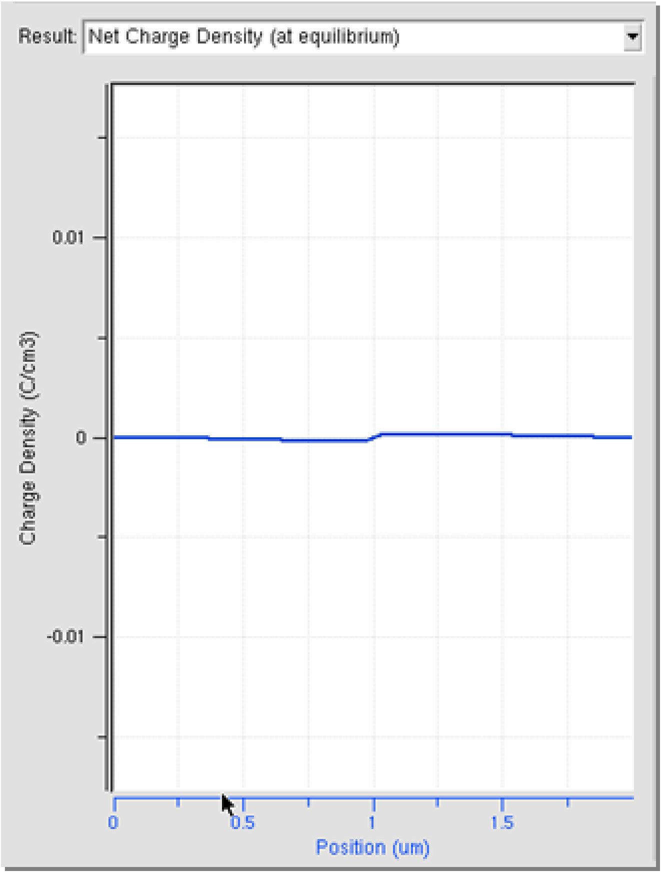


$$qN_A = 0.016\ C/cm^3$$

$$W_D = \sqrt{\frac{2\varepsilon_{Si}\left(N_A + N_D\right)V_{bi}}{qN_A N_D}} = 0.15\,\mu m$$

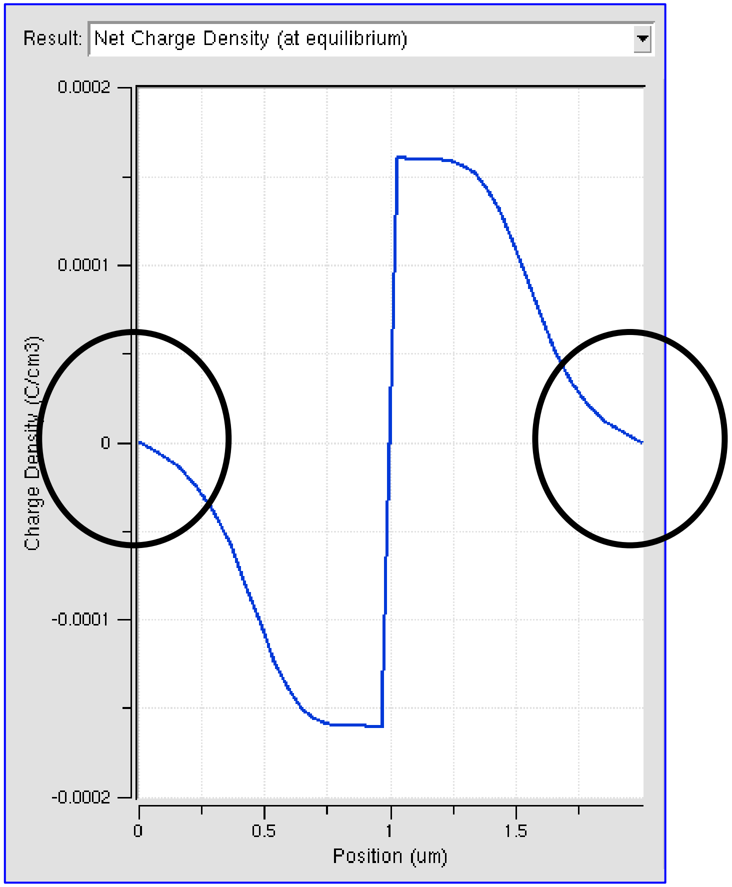
$$W_P = W_N = \frac{W_D}{2} = 0.075\,\mu m$$

lower the doping density

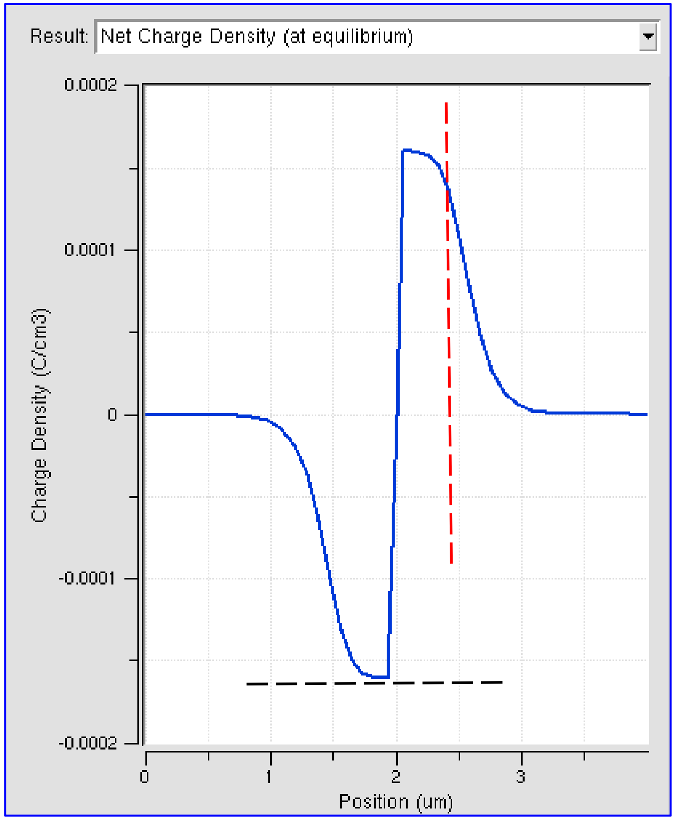


$$N_A = N_D = 10^{15}\ cm^{-3}$$

change the vertical scale



change the horizontal scale



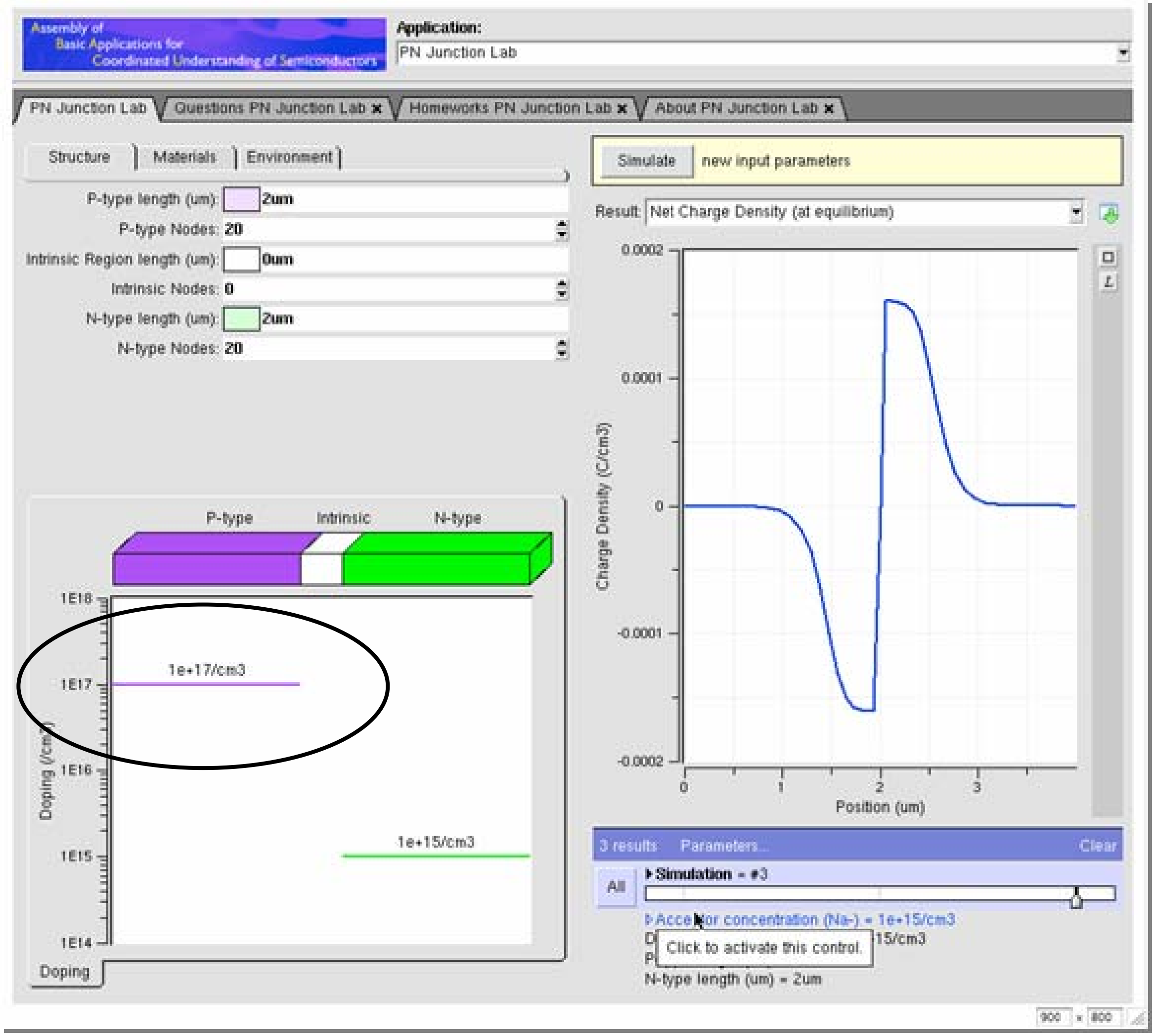
$$N_A = N_D = 10^{15}\ cm^{-3}$$

$$qN_A = 0.00016\ C/cm^3$$

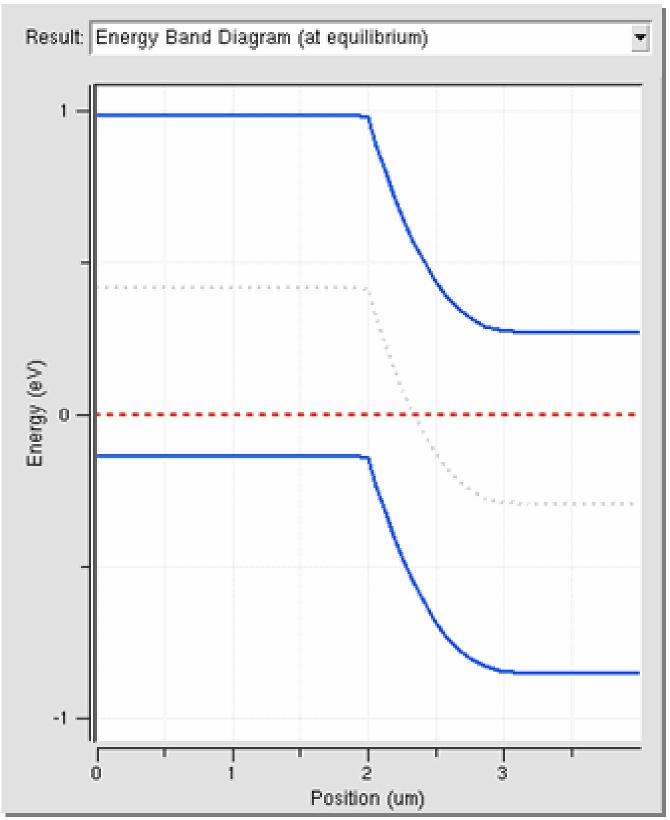
$$W_D = \sqrt{\frac{2\varepsilon_{Si}\left(N_A + N_D\right)V_{bi}}{qN_A N_D}} = 0.88\,\mu m$$

$$W_P = W_N = \frac{W_D}{2} = 0.44\,\mu m$$

asymmetric junction

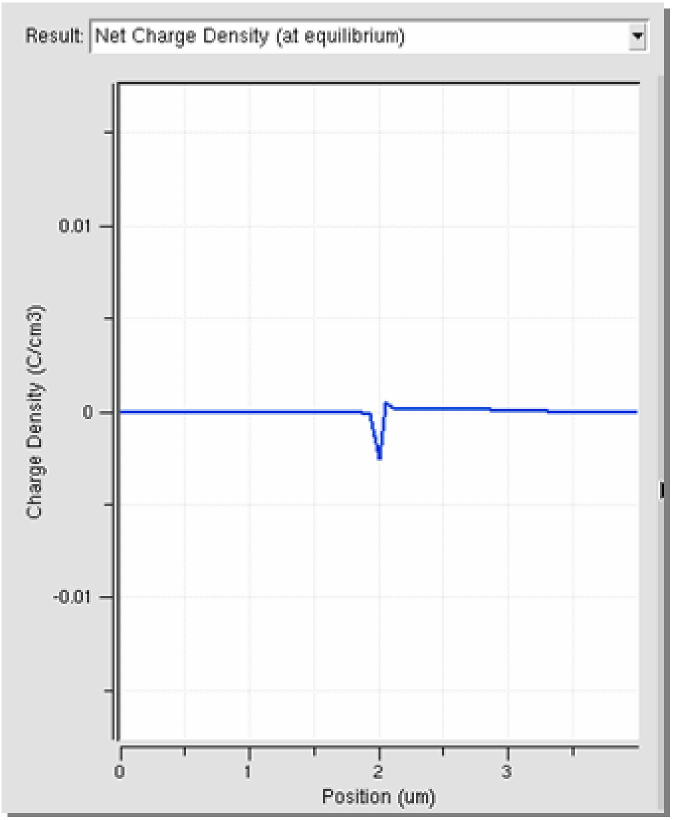


asymmetric junction



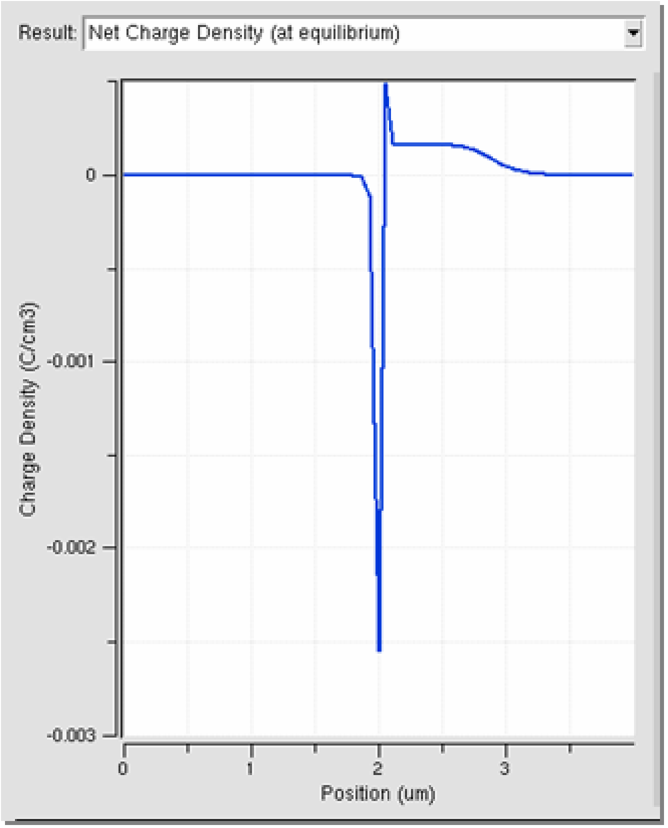
band bending all on lightly doped side

space charge density



need to change scales

space charge density



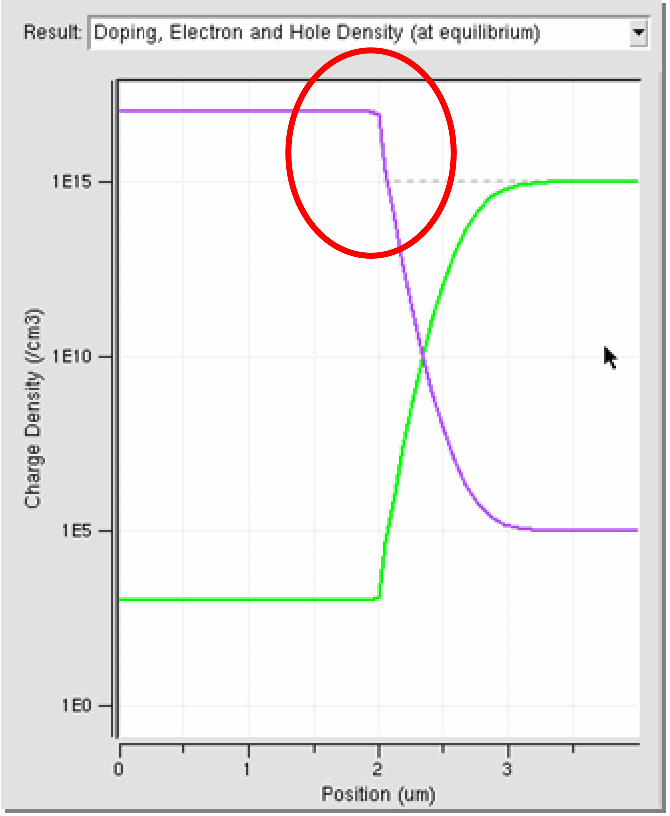
$$N_A = 10^{17}\ cm^{-3}$$

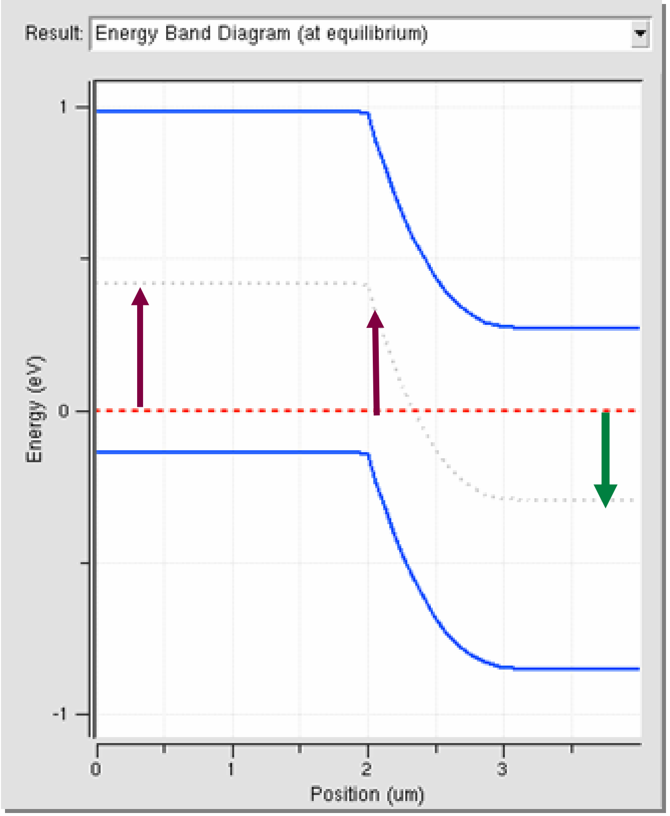
$$qN_A = 0.016\ C/cm^3$$

$$N_D = 10^{15}\ cm^{-3}$$

$$qN_D = 0.00016\ C/cm^3$$

inversion layers in pn junctions





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