One-dimensional Finite Difference Simulations of Uniform and Gaussian doped PN junctions

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Abstract: One-dimensional simulations based on a finite difference method were used to investigate the carrier distribution in a PN junction device. Materials used in the study are silicon doped with arsenic for N-type and boron for P-type. In the first section, the uniform doping profile with different acceptor concentrations from 10^{16} to 10^{19} cm^{-3} was computationally investigated. Simulation results were compared with those obtained from theoretical analysis. In the second section, more realistic Gaussian doping distribution was explored. N-type silicon was uniformly doped with a concentration of 10^{16} cm^{-3}; and P-type silicon was doped with the maximum acceptor concentration of 10^{19} cm^{-3}. Simulations show that the internal electric field has combined characteristics between abrupt and linear junctions.

Introduction and Ojective

Due to the carrier distribution is non-linear, the simulation is important. In the objective of this project are

- To delvelop the model of semiconductor using finite difference in one-dimesion
- To study the carrier distribution under the influence of uniform and Gaussian doping profile

Simualtion Process

The model of PN junction devices

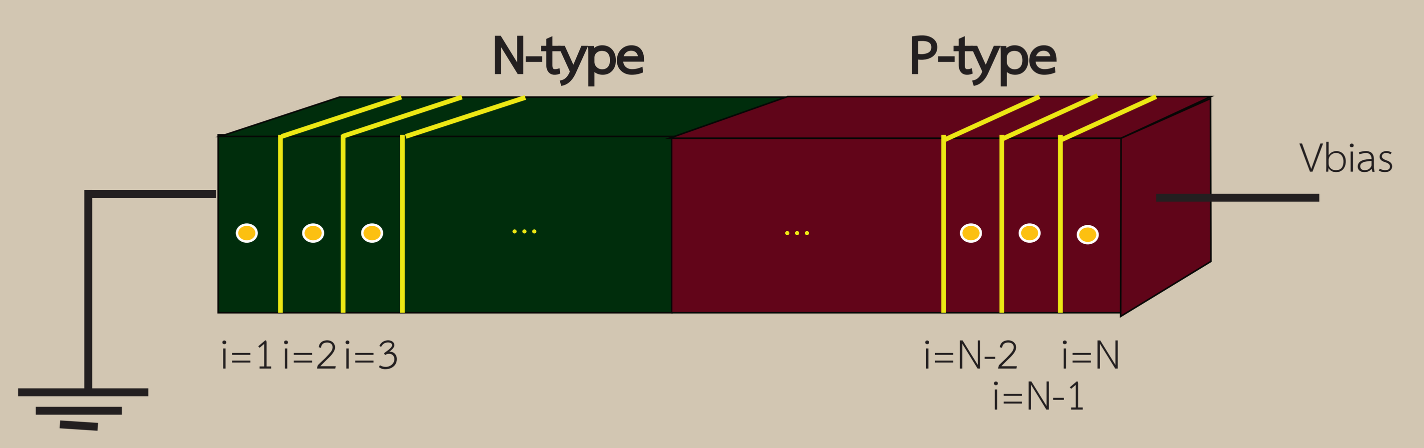

Figure 1 the model of semiconductor considered in one-dimensional discretization. It is aimed to study the carrier distribution at equilibrium state where both ends are grounded.

Basic Equations

Poisson's Equation

$$\frac{d^2\psi}{dx^2} = \frac{q}{\varepsilon}[(n - ND) - (p - NA)]$$

$$E = -\frac{d\psi}{dx}$$

$$J_n = q\mu_n nE + qD_n\frac{dn}{dx}$$

$$J_p = q\mu_p pE + qD_p\frac{dp}{dx}$$

Current Density Equation

$$\frac{\partial n}{\partial t} = -\frac{1}{q}\frac{\partial J_n}{\partial x}$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\frac{\partial J_p}{\partial x}$$

Continuity Equation

Figure 2 the process flow of simulation

The finite difference approximation can be demonstrated by

$$\frac{d\psi}{dx} \approx \frac{\psi_{i+1} - \psi_{i-1}}{2\Delta x}$$ first derivative approximation

$$\frac{d^2\psi}{dx^2} \approx \frac{\psi_{i+1} - 2\psi_i + \psi_{i-1}}{\Delta x^2}$$ second derivative approximation

Simulation results were then campared with those of theoretical analyses.

$$V_{bi} = \psi_n - \psi_p = \frac{kT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right)$$ built-in potential approximation

$$V_{bi} = \frac{1}{2}WE_m$$ depletion region approximation

$$E_m = q\frac{N_D x_n}{\varepsilon_s} = q\frac{N_A x_p}{\varepsilon_s}$$ maximum electric field approximation

Uniform Doping

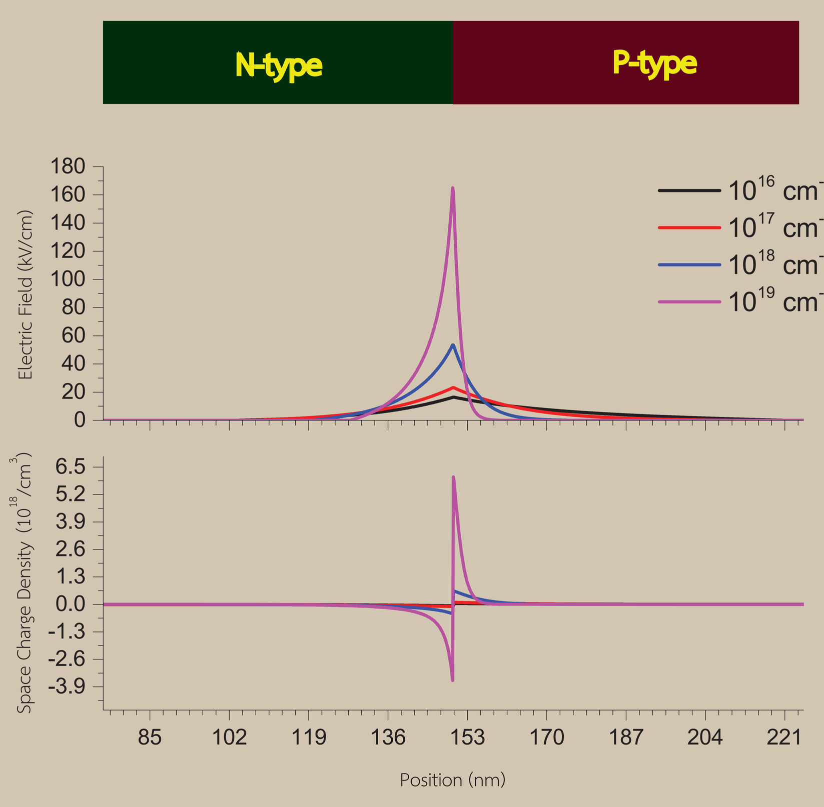

Figure 3 Carrier and Space Charge Distributions with different acceptor concentrations

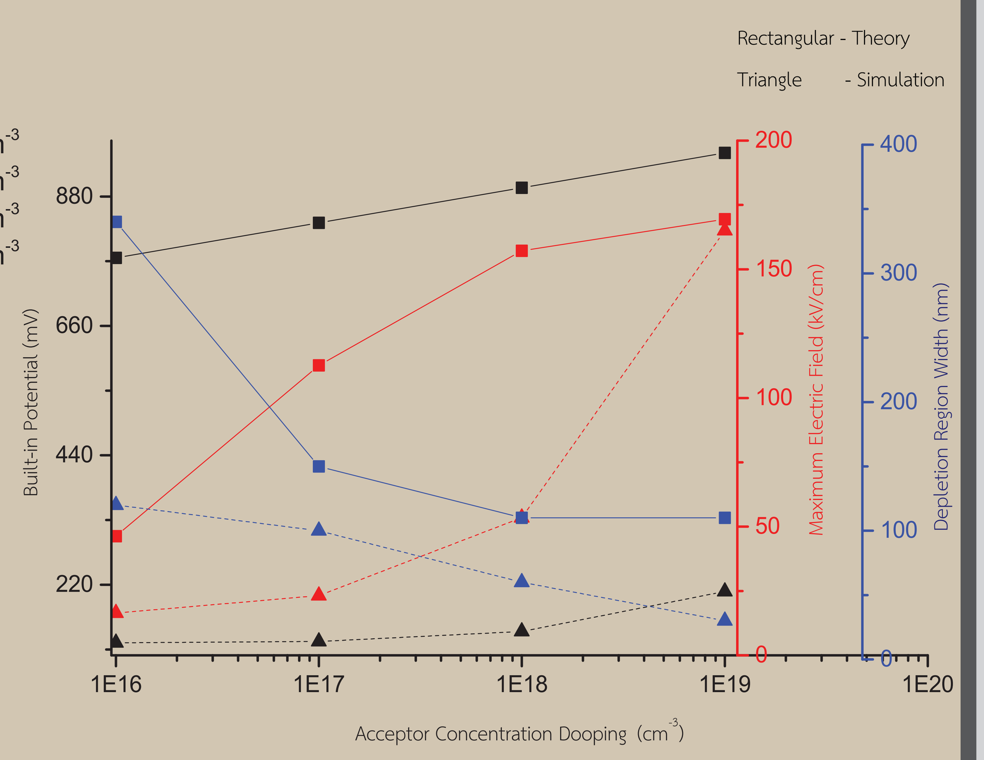

Figure 4 Simulation results and theoretical calculations of Maximum Electric Field, Built-in Potential and Depletion Region Width as a funciton of Acceptor Concentrations

Gaussian Doping

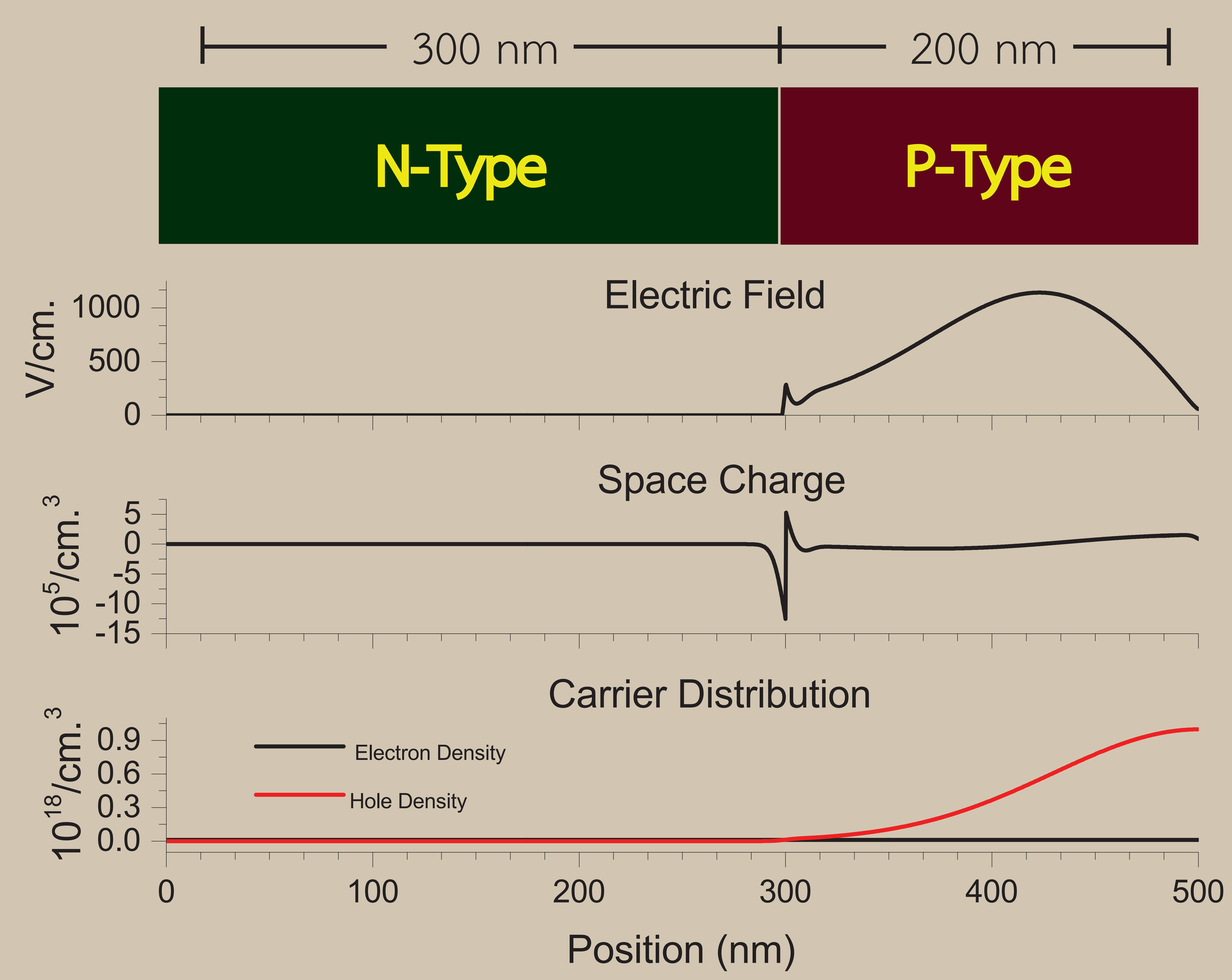

Figure 5 Electric Field, Space Charge and Carrier Distribution of a Gaussian Doped PN junction.

Conclusion

From the simulation results in first section, they were compared with theoretical analysis. The built-in potential and maximum electric field are raise up when the acceptor concentration is increase. On the contrary, the width of depletion region is smaller when we increase the acceptor density. The another section, we see that the electric field is combined with the characteristic between abrupt and graded linear junction.

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