A One Dimensional BCCD Model

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Abstract

Two and three dimensional simulation of CCD structures are useful tools in designing and analysing complex CCD structures. Occasionally, however, especially for preliminary designs and simple analysis, parameters such as charge storage capacity, channel potential distribution and capacitance values are required. Although more sophisticated simulation tools will yield these design parameters, in many cases simpler tools would suffice.

Simple modeling of the buried channel CCD has been reported recently that enables determination of vertical channel potential distributions with or without charge in the channel. This modelling has been based on the depletion approximation using uniform doping profiles.

We presents a model that uses gaussian profiles with offset peaks more typical of profiles found with ion-implantation. In addition, the presented model simulates the effect of thermal drive cycles by altering the standard deviation of the guassian distribution. The effect of charge storage within the channel is also simulated. With this model accurated parameters of the buried channel CCD may be determined quickly compared to 2-dimensional simulations and to a level of accuracy sufficient for preliminary design. Limitations are that narrow width and short channel effects (2-dimensional effects) cannot be simulated.

1D BURIED CHANNEL CCD MODEL SUMMARY

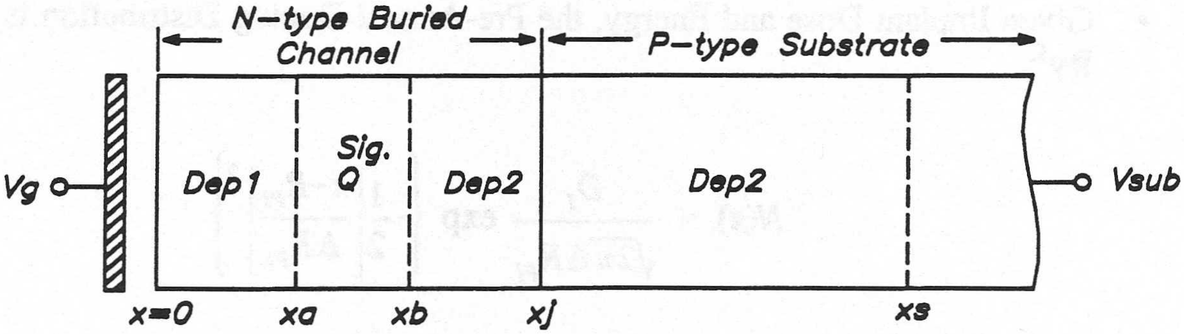
- Solves Poisson's Equation Using the Depletion Approximation
- Determines Potential Distribution with Channel Signal Charge
- Uses Doping Profile Determined by Any Number of Ion Implants of Either Species, Annealed With or Without Reflection of Dopant Off of the *SiO_2/Si* Interface
- If Dopant is Reflected Off of the Interface During Annealing, the Imlanted Dose from Before to After the Thermal Cycle
- Top Depletion and Back Depletion Capacitances are Calculated. These can be used to Calculate Subthreshold Slope.
- Parameters Obtained Depend on Applied Boundary Conditions

Ex: Given V_g, V_{sub}, V_{max} one obtains N_{sig}

Given V_g, V_{sub}, N_{sig} one obtains V_{max}

Given V_g, V_{sur}, N_{sig} one obtains V_{max}

PHYSICAL STRUCTURE



- Given the Annealed Doping Profile and x_a, x_b (signal charge is stored between x_a and x_b) and x_s)edge of depletion region in the substrate), Poisson's Equation Using the Depletion Approximation is Solved for Electric Field and then Potential for Four Regions:

$$\textit{Region } 1: \quad \frac{d^2x}{dx^2} = 0 \; ; \quad t_{ox} < x < 0$$

$$\textit{Region } 2; \quad \frac{d^2V}{dx^2} = \frac{-qN(x)}{\epsilon_s}; \quad 0 < x < x_a$$

$$\textit{Region } 3; \quad \frac{d^2V}{dx^2} = 0; \quad x_a < x < x_b$$

$$\textit{Region } 4; \quad \frac{d^2V}{dx^2} = \frac{-qN(x)}{\epsilon_s}; \quad x_b < x < x_s$$

- Double Integration Yields Eight Constants of Integration. To Have a Unique Solution Requires Eight Boundary Conditions which Consist of:

  V_g, Conservation of Electric Flux Density and Equal Potential Across the Interface, Equating of Electric Field and Potential Across x_a, Equating of Electric Field and Potential Across x_b and Zero Electric at x_s

DOPING DISTRIBUTION

- Given Implant Dose and Energy, the Pre-Anneal Doping Distribution is Given By[1]:

$$N(x) = \frac{D_I}{\sqrt{2\pi}\,\Delta R_{PI}} \exp\left\{-\frac{1}{2}\left[\frac{x-R_{PI}}{\Delta R_{PI}}\right]^2\right\}$$

- After Annealing, Given the Diffusion Co-efficient(*D*) and Time(*t*), The Distribution is:

$$N(x) = \frac{D_I}{\sqrt{2\pi}(\Delta R_{PI}^2+2Dt)^{1/2}} \exp\left\{-\frac{1}{2}\left[\frac{x-R_{PI}}{(\Delta R_{PI}^2+2Dt)^{1/2}}\right]^2\right\}$$

- The Doping Distribution Expression is Modified for Reflection of Dopant Off of the Interface (*@x=0*):

$$N(x) = \frac{D_{IMOD}}{\sqrt{2\pi}(\Delta R_{PI}^2+2Dt)^{1/2}} \times$$

$$\left(\exp\left\{-\frac{1}{2}\left[\frac{x-R_{PI}}{(\Delta R_{PI}^2+2Dt)^{1/2}}\right]^2\right\} + \exp\left\{-\frac{1}{2}\left[\frac{x+R_{PI}}{(\Delta R_{PI}^2+2Dt)^{1/2}}\right]^2\right\}\right)$$

- D_{IMOD} is D_I Modified so that the Total Dose in the Silicon From Before to After the Anneal is Conserved.

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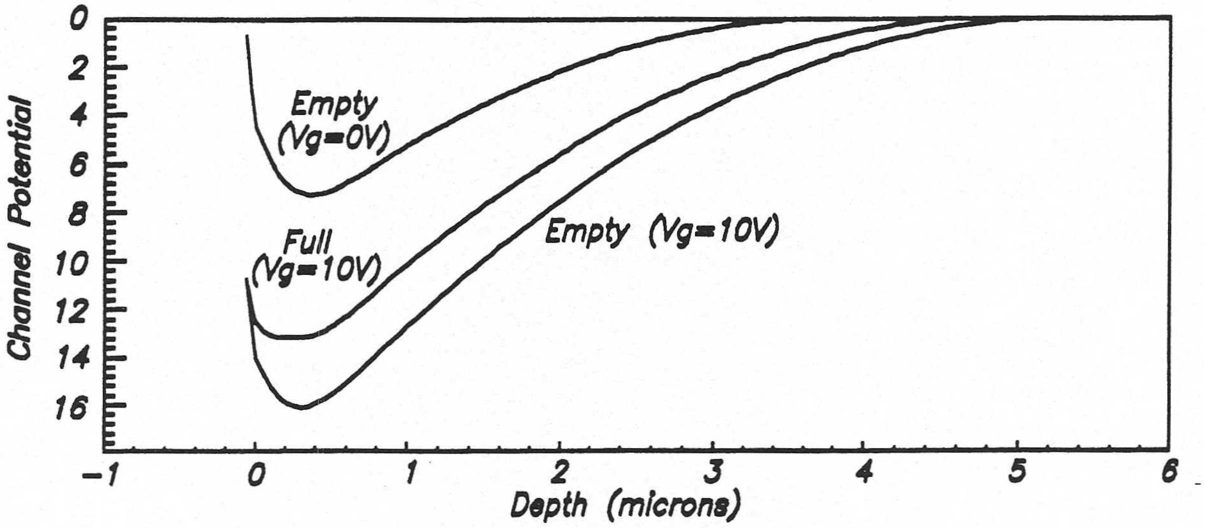
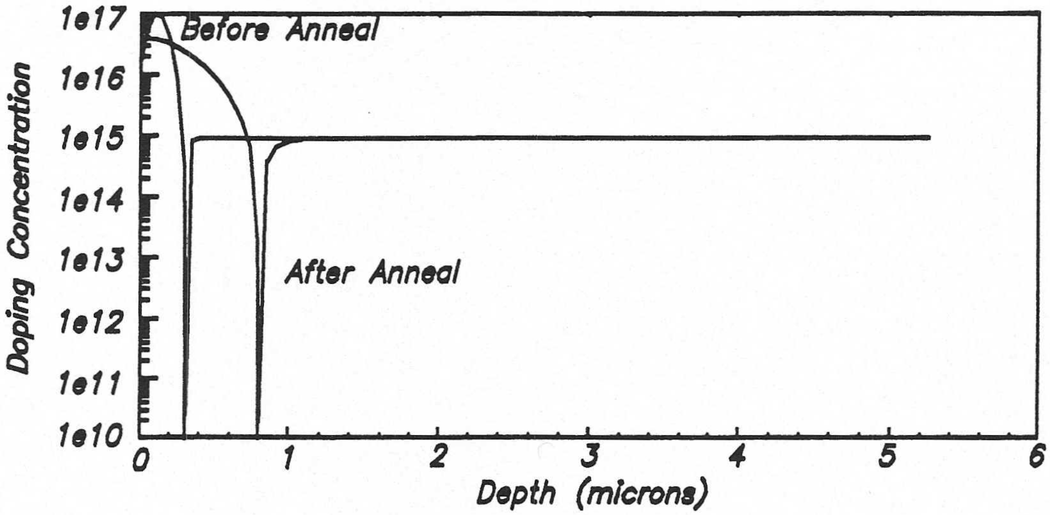
[1] Reference: S.K. Ghandi, "VLSI Fabrication Principles", John Wiley and Sons, NY, 1983.

SIMULATION RESULTS





INPUT DATA:
Vg - gate voltage (V) : 10.000
Vfb - flatband voltage (V) : -0.750
Vsub - substrate voltage (V) : 0.000
Nsig - signal charge (um^-2) : 5000.0
Tox - oxide thickness (A) : 660
IITox - ion implantation oxide thickness (A) : 800
Nsub - substrate doping (cm^-3) : -9.00e+014
nsteps - number of steps : 100
Input Dose: D[0]= -1.5e+011, D[1]= 1.7e+012, D[2]= 0.0e+000

CALCULATION RESULTS:
Total Effective Dose (cm^-2) : 1.499e+012
Cox (fF/um^2) : 0.510
Cdep1 (fF/um^2) : 0.713
Cdep2 - (fF/um^2) : 0.023
Cg - (fF/um^2) : 0.022
Ceff - (fF/um^2) : 0.320
Xj - junction depth (um) : 0.798
Xs - depth of substrate depletion (um) : 4.850
Xa - top charge depth (um) : 0.148
Xb - bottom charge depth (um) : 0.322
Vmax - maximum potential (V) : 13.136
Vsur - surface potential (V) : 12.517
Vdiff - difference potential (V) : 0.620