Numerical Simulation of the MOS System with Interface Traps

Michael Gaitan
National Bureau of Standards
Semiconductor Electronics Division
Gaithersburg, Md. 20899

Abstract

The MOS system with interface traps is simulated in one dimension using numerical analysis techniques. To model this system, the Poisson equation with a nonlinear boundary condition is solved. The technique uses Newton's iteration method to solve Poisson's equation in the semiconductor by finite differences with nonconstant grid [1]. The nonlinear boundary condition is solved using Brient's iteration method [2]. This method is shown to converge for interface trap densities of up to 10^{13} $cm^{-2}eV^{-1}$ which would exceed the semiconductor depletion layer charge.

Numerical Simulation of the MOS System with Interface Traps

Michael Gaitan
National Bureau of Standards
Semiconductor Electronics Division
Gaithersburg, Md. 20899

Extended Abstract

To accurately model the quasi-static CV characteristics of the MOS system, interface traps must be included. Interface traps lead to a nonlinear boundary condition. Assuming that any fixed charge in the oxide region and the interface traps can be approximated by a sheet of charge at the Si-SO_2 interface, the boundary condition is the discontinuity of the normal component of the displacement field due to charge at the interface,

$$C_{ox}(\psi_s - V_g) = Q_{si}(\psi_s) + Q_s(\psi_s). \tag{1}$$

C_{ox} is the oxide capacitance, V_g is the applied gate voltage, Q_s is the total charge at the interface, $Q_{si} = \epsilon_{si}\frac{\partial\psi_s}{\partial x}$ is the charge in the silicon, and ψ_s is the semiconductor surface potential from Possion's equation.

The charge at the interface, Q_s, is the sum of the oxide fixed charge, Q_f, and the interface trapped charge, Q_{it}, which is non-linear in ψ_s,

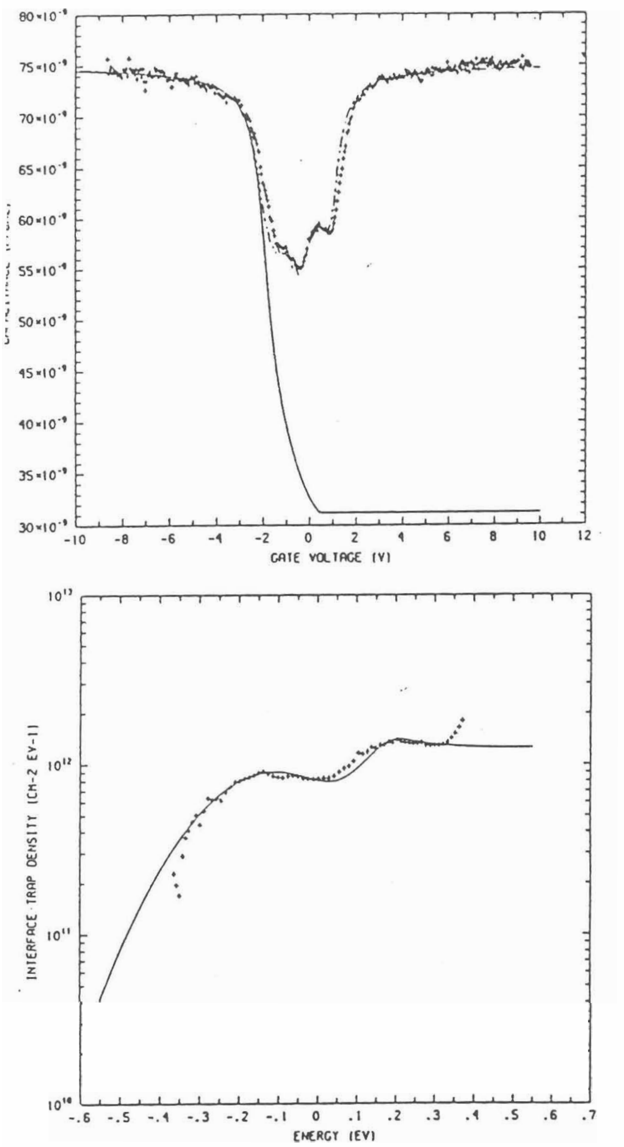
$$Q_s = Q_f + Q_{it}(\psi_s) = Q_f + q\int_{E_v}^{E_c}\Big(D_{it}^d(E)[1 - \mathrm{f}(E,\psi_s)] - D_{it}^a(E)\mathrm{f}(E,\psi_s)\Big)dE. \tag{2}$$

where f is the fermi function, E_c and E_v are the energies of the conduction and valence bands, D_{it}^d and D_{it}^a are the distributions of the donor and acceptor like interface traps, and q is the magnitude of the electronic charge.

The boundary condition (1) becomes dominated by Q_{it} and highly nonlinear in ψ_s for large values of interface traps and cannot be solved by including it in the system of linear equations derived from the Poisson equation. Using linearization oscillations are observed and convergence is never reached. To achieve convergence for any arbitratry interface trap distribution the boundary condition must be solved independently. Using Brient's iteration technique Q_s and Q_{si} are solved for each given surface potential ψ_s until the nonlinear boundary condition (1) is satisfied.

Figures (1) and (2) show the results of this solution technique. Figure (1a) models a device with a 460 Å oxide, p-type doping, and an interface trap distribution with an acceptor peak of 1.25×10^{12} cm^{-2}eV^{-1} shown in figure (1b). The dashed line in figure (1a) is the modeled quasi-static capacitance response and the solid line is the modeled ideal high frequency capacitance response. The '+' marks are measured data from an actual device. Figure (2a) models a device with 500 Å oxide, nonconstant p-type doping, and an interface trap

distribution with a acceptor peak of 10^{13} $cm^{-2}eV^{-1}$ shown in figure (2b). Figure (2) demonstrates that even with an extremely high interface trap distribution, convergence is guaranteed.



(a)

(b)

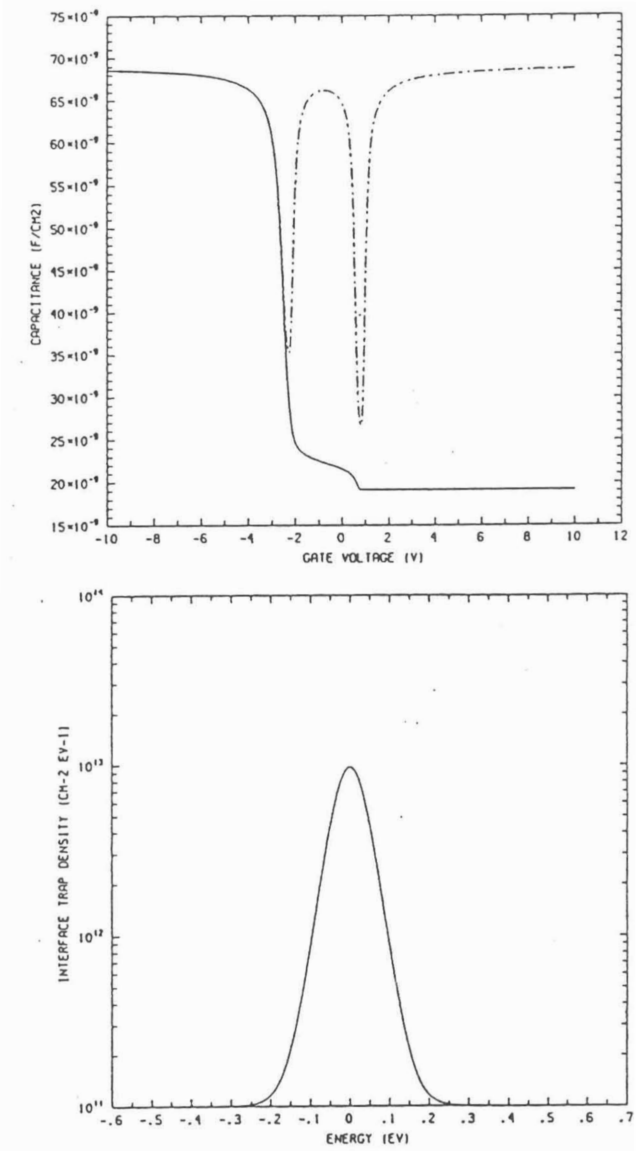


Figure 1. (a) high frequency and quasi-static response for a p-type device with 460 Å oxide and interface trap distribution (b) with acceptor peak of 1.25×10^{12} $cm^{-2}eV^{-1}$. Doping is constant with an acceptor concentration of 1.5×10^{16} cm^{-3}. The '+' marks are measured from an actual device.

Figure 2. (a) high frequency and quasi-static response for a p-type device with 500 Å oxide and interface trap distribution (b) with donor peak of 10^{13} $cm^{-2}eV^{-1}$. Doping is nonconstant with an average value of 5.0×10^{15} cm^{-3}.

References

[1] Kurata, M., "Numerical Analysis for Semiconductor Devices", Lexington Books, P37 (1982).

[2] Brient, "Algorithms for Minimization Without Derivatives", Prentice-Hall, P188 (1973).