Two-dimensional Numerical Modelling of MOS Test-Structures

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Outline

- Introduction
- Experimental Measurements @UH
- Device Structure and Physical Models
- Simulation Procedure
- Simulation Work Done :

Comparison Data to Simulation

"Two-Dimensional Numerical Modelling of MOS Test-Structures for C-V and G-V Characterization of Gated Diode"

- Unirradiated
- Irradiated (0.5 MGy – 10 MGy)

Introduction

Requirements XFEL :

Flux of 12 keV photons: 10^{16} γ/pixel → 1 GGy [10^9 J/kg]

Radiation damage and its impact on sensor performance:

- Bulk damage not expected (threshold is 300 keV)
  - only damage in SiO_2 and Si-SiO_2 interface important → surface damage
- charge build-up in oxide
  i.e. N_{ox} (oxide trapped charge density and
  build –up of of interface trap density (N_{it}).
  → shift of flatband voltage (V_{fb})

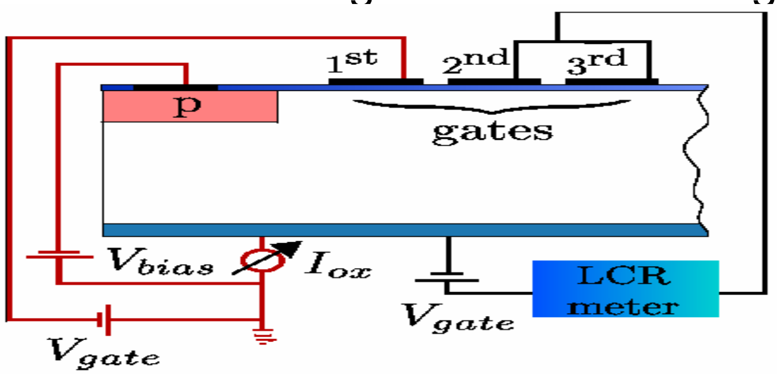
→ high field (breakdown regions) at critical corners

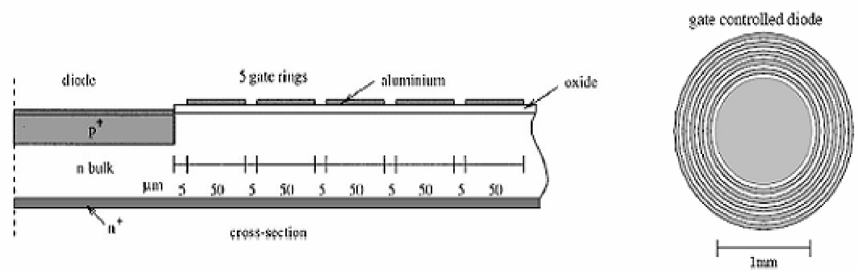
→ dark current →increases noise

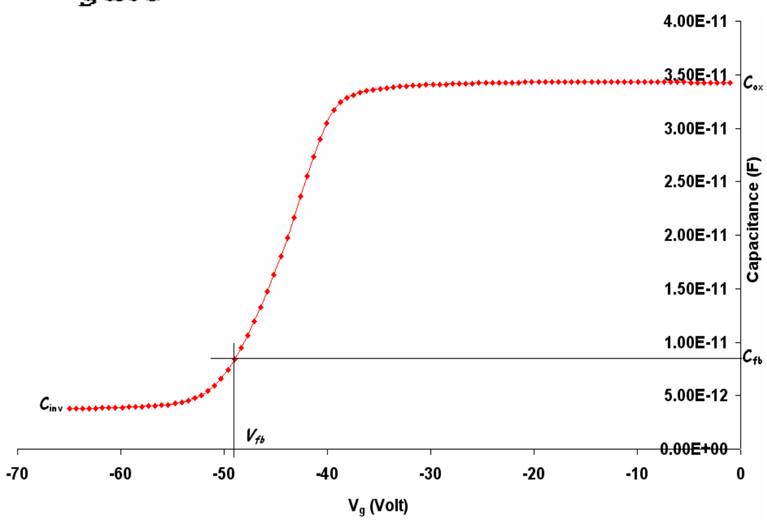
Experimental measurements @UH

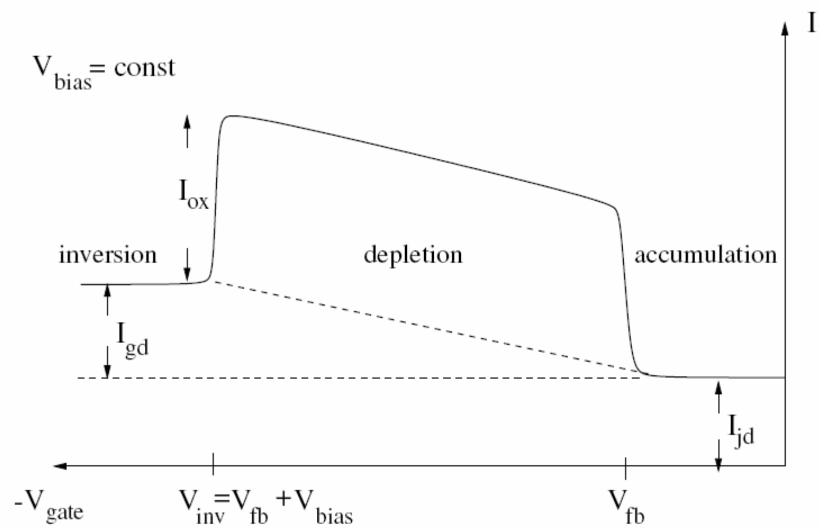
Circuit for I/V (I_{ox}) and C/V (V_{fb}, C_{ox}, C_{inv}, C_{fb}) measurement &
--- Measurement for G/V (N_{it})/TSC (N_{it}, σ_{eff}, energy level) of gated diode

- Test structure: gated diode with 5 gate rings for surface damage









Device simulation

Aim: **Detailed simulation of sensor including radiation damage effects (N_{ox},N_{it})**

Software: **2-D Device simulation with ISE T-CAD DESSIS version 2005.10 (Device Simulation for Smart Integrated Systems)**

Device structure and physical models

MOS 50 x 300 micron

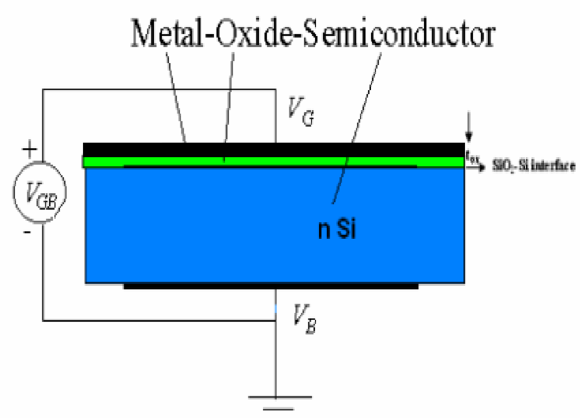
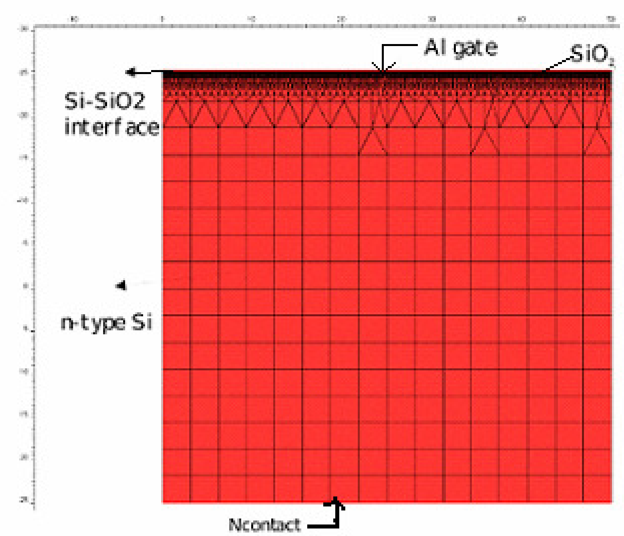


Fig : Cross-section of MOS structure used in the present simulation work.

→



Physics models used:

- SRH recombination
- Auger recombination
- Impact ionization
- Surface recombination
- Gate current (Lucky) model
- Trap models
  - solving Poisson and electron/hole current-continuity equations
  - dependence of life time of charge carrier (τ) on interface trap density (N_{it}) taken into account.

and doping dependent mobility and high field saturation model, band to band tunneling

AIM: *Describe C/V and G/V characterstics vs. frequency*

How Parameters used in the present work:

From measurement: N_{ox} (oxide trapped charge density), N_{it} (interface trap density), I_{ox} (surface generation current)

Optimize to describe data: E_t (trap energy), trap type

Input physical and geometrical parameters used for MOS test-structures AC simulation:

- Area of gate= 0.0404 mm^2 (taken from experimental measured gate diode)

- t_{ox} =400 nm (oxide thickness)

-N_D = 1.28 x 10^12 /cm^3 (Doping concentration for n-type bulk Si)

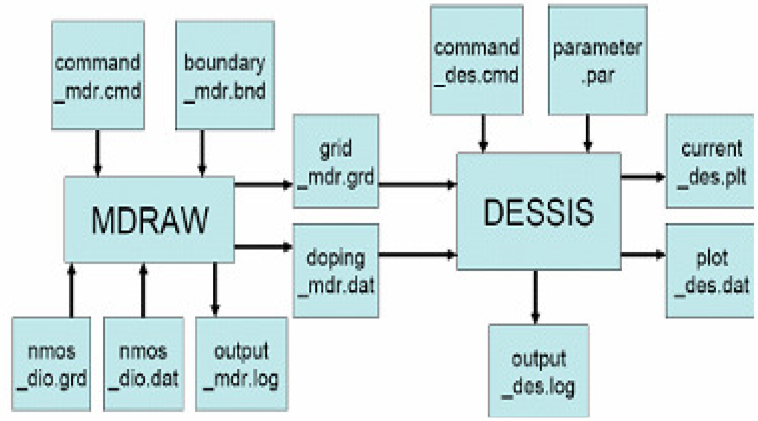
-AC frequency : 10-800 kHz with 0.1 ac voltage

- σ_{eff} (n/p) =7 x10^-17 cm ^2 (effective capture cross-section for charge carriers)

Simulation procedure

Procedure

1. Design structure in MDRAW
2. Feed results into DESSIS
3. Combine simulation of device (DESSIS) and circuit (SPICE)



mixed-mode simulations: Device using dessis and Circuit (SPICE)

1. AC analysis: to obtain small signal admittance Y matrix - current response at a node to a small signal voltage at another node of the form:

$$i = \mathrm{Y} \times v = \mathrm{A} \times v + \mathrm{j}\omega\mathrm{C} \times v$$

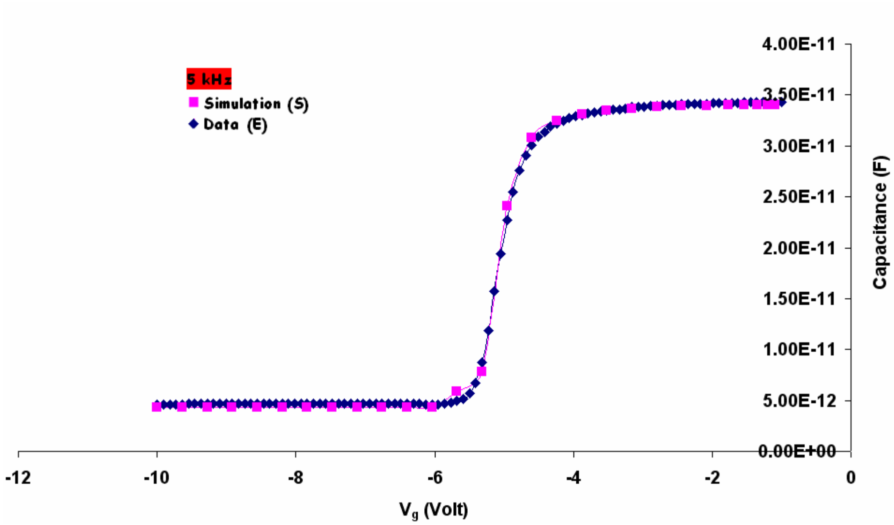
i = small signal current vector (at all nodes) $\rightarrow C_p,\ G_p$

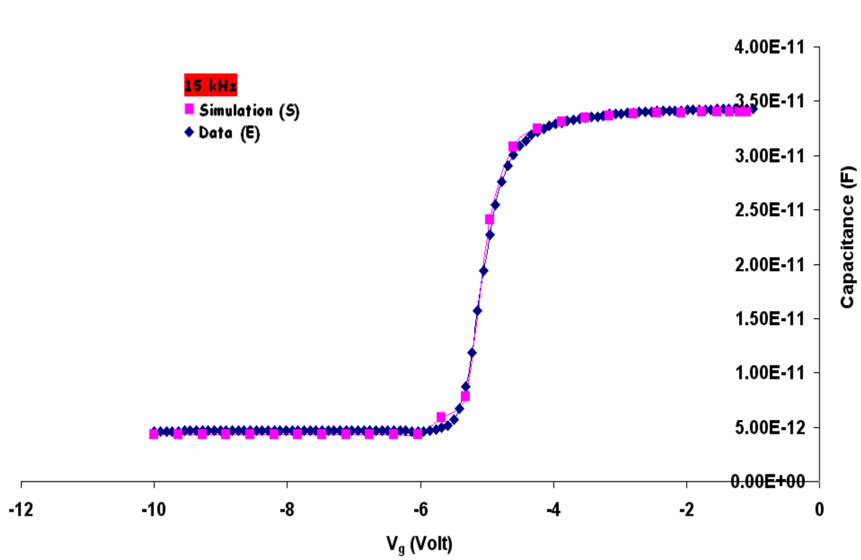
v = voltage vector

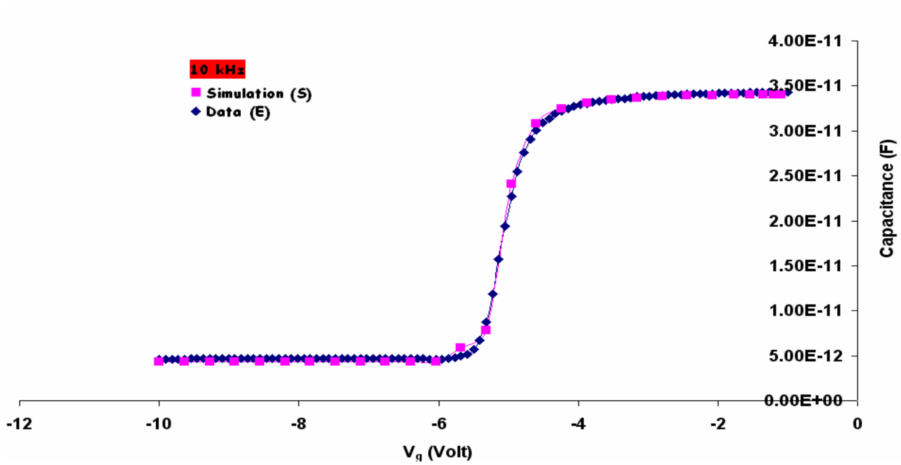
DESSIS output is conductance matrix and capacitance matrix.

→ **Compare results to simple analytical calculations for cross-check**

Comparison data to simulation : unirradiated gated diode vs. frequency



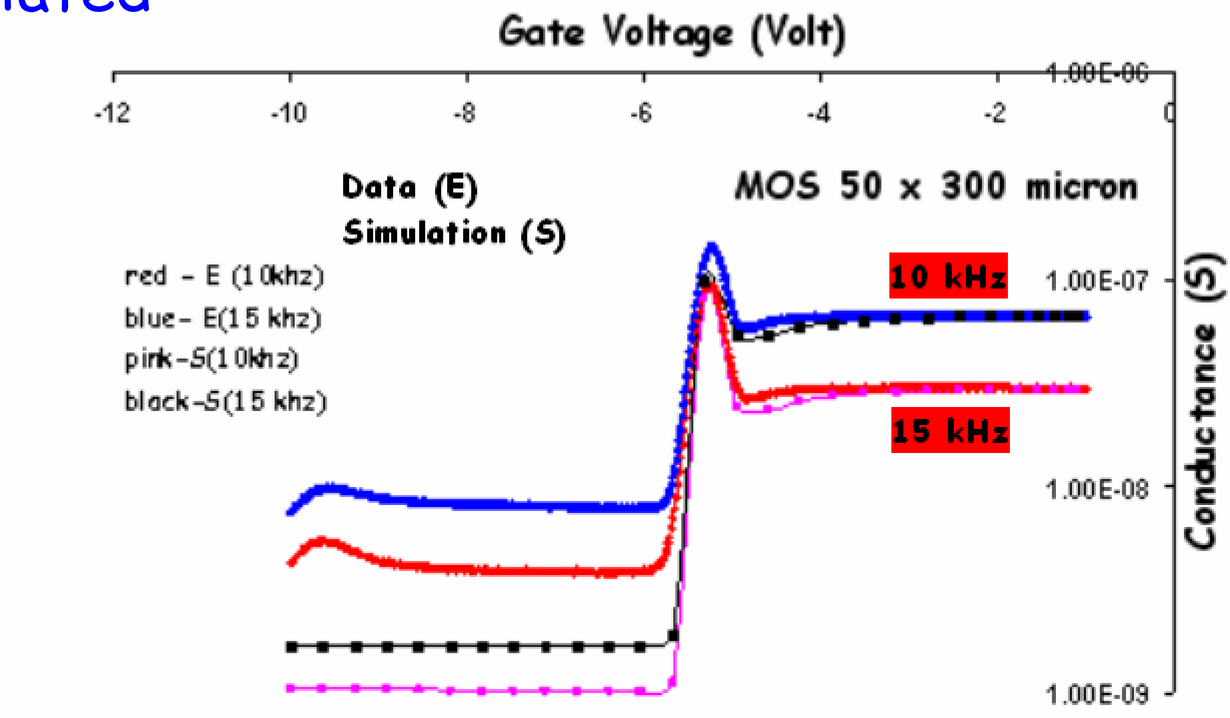




- C/V curve almost agrees with experimental result at three different frequencies

  → C/V curve independent of frequency

Unirradiated



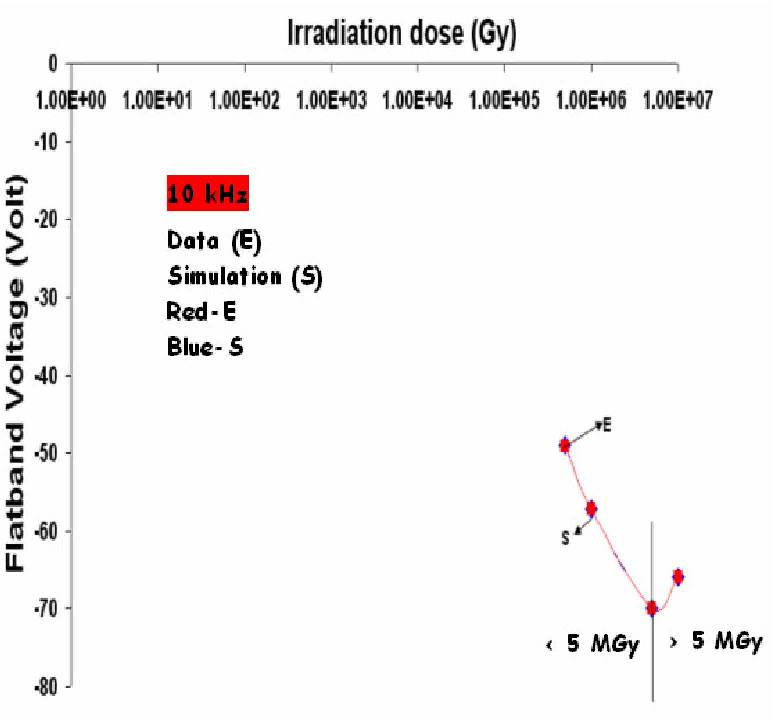
- ***G/V curve very sensitive to interface traps***
  → ***from shape of curve → Acceptor traps***

- ***Good description of G/V curve in***
  - ***Accumulation***
  - ***Flatband***

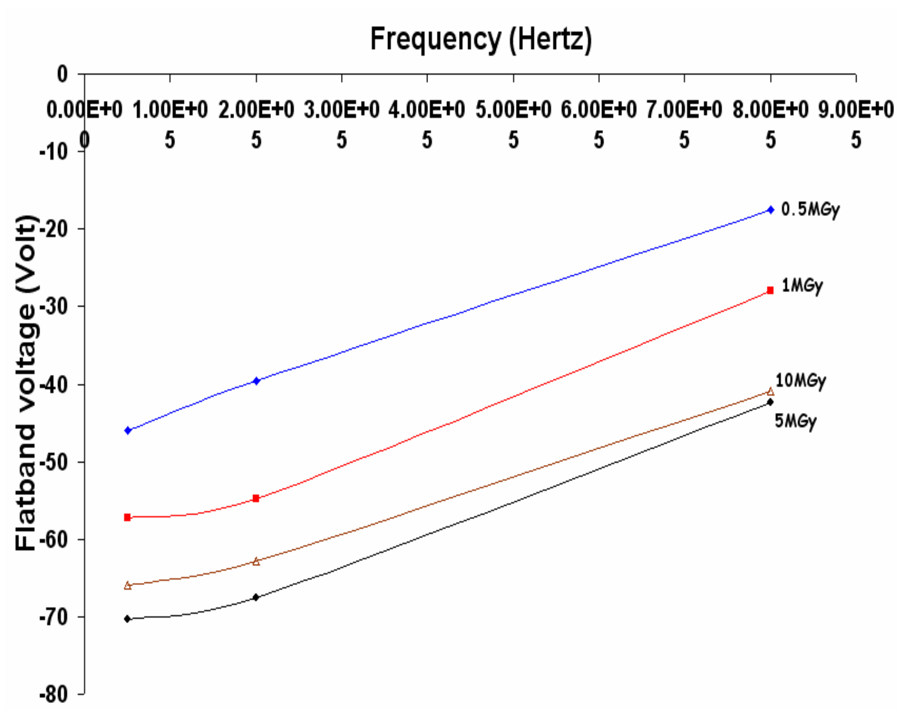
  → In inversion region: disagreement

Simulation of irradiated device (C/V)

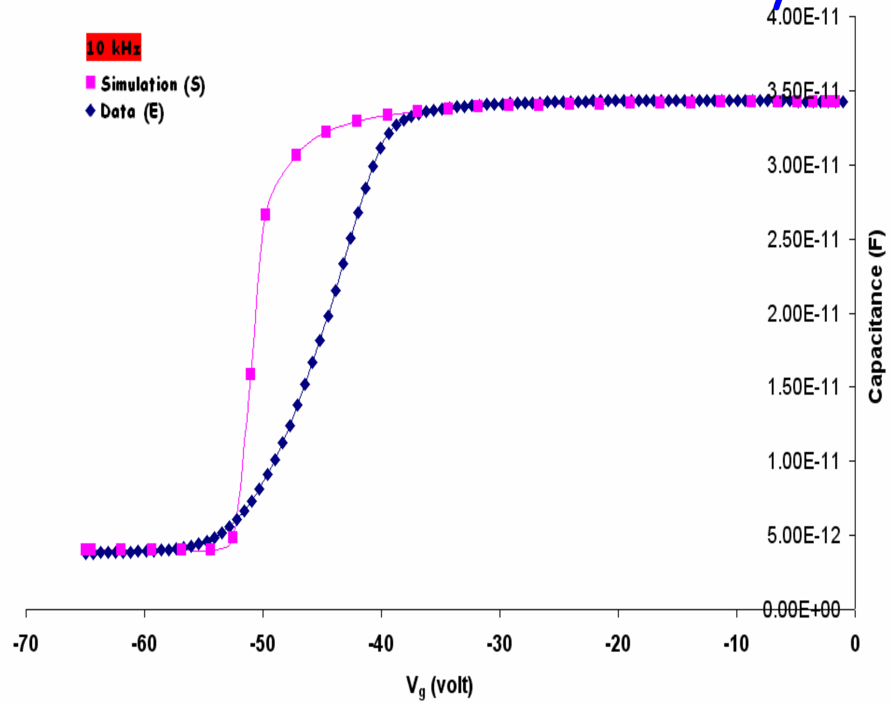
- **Use measurements to estimate N_{ox} and N_{it}**
  → Simulation agrees with data



Simulated frequency dependence of V_{fb}



Comparison of data to simulation: 0.5 MGy irradiated gated diode



Conclusion: irradiated

- **V_{fb} increases up to 5 MGy then decreases (if measurement after irradiation)**
- **V_{fb} decreases with frequency for all doses**
- **Good description of C/V curve in accumulation and inversion**
- **Shape of curve not understood (uniformity of irradiation, properties of traps)**
- **G/V curve is problem.**

Summary

- Simulation for C/V characteristics is in good agreement with experimental results for unirradiated and irradiated gated diode but for irradiated gate diode, difficulty to reproduce C/V curve!

- G/V characteristics is very sensitive to type of interface trap and interface trap density at different frequency for unirradiated and irradiated gate diode .

Back-up slides

Analytical calculation and High frequency model for C/V characterization of MOS

The change of V_{fb} is a direct measure for the concentration of ionization induced positive oxide charges N_{ox} trapped in the oxide, → $\Delta V_{fb} = \frac{q_0 d}{\varepsilon_0 \varepsilon_{ox}} \cdot \Delta N_{ox}$

The interface generation current is caused by generation of charge carriers in the interface, → $I_{ox} = q_0 n_i S_0 A_{gate}$

where n_i is the intrinsic charge carrier concentration, A_{gate} the gate area and S_0 the interface recombination velocity. Assuming a homogeneous distribution of the interface states across the band-gap, S_0 is given as → $S_0 = \sigma v_{th} \pi k_B T D_{it}$

with $\sigma = \frac{1}{2}\sqrt{\sigma_n \sigma_p}$ being the effective capture cross-section for electrons and holes of the interface trapping centers, v_{th} the thermal velocity of the minority carriers, k_B the Boltzmann constant, T the absolute temperature and D_{it} the interface state density in $cm^{-2}eV^{-1}$

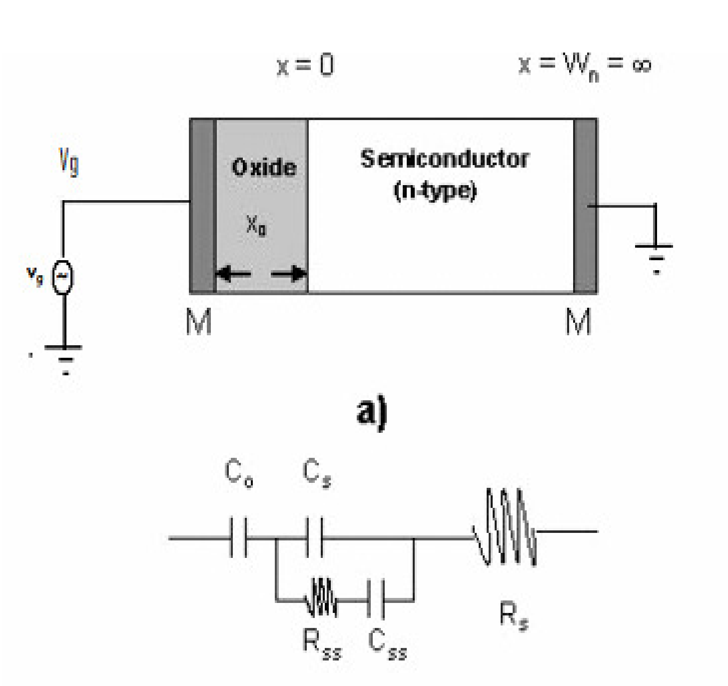


Fig:MOS HF equivalent model.

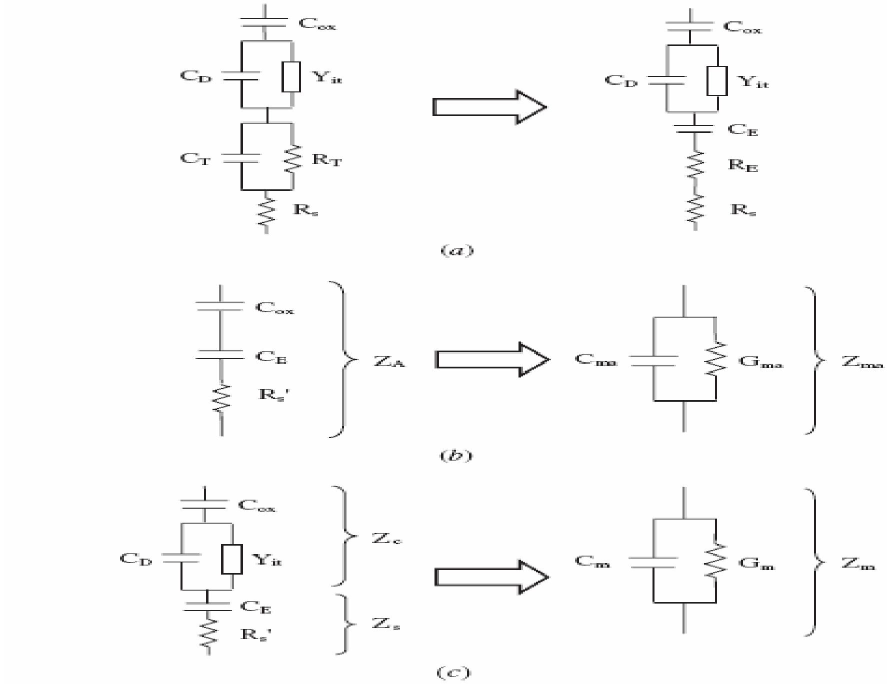


Fig: High frequency model in the presence of unwanted lossy layer at interface (extension of ***Nicollian***, E. H. / ***Brews***, J. R. MOS (Metal Oxide ***Semiconductor***) Physics and Technology).

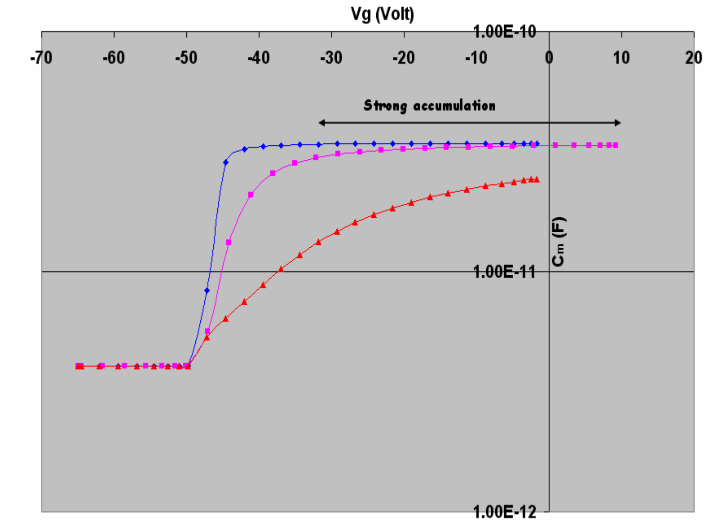
→ Where, C_{ox} , C_D, Y_{it}, C_T, R_T , C_E, R_E, R_s, R_s', C_{ma}, G_{ma}, C_m and G_m are known as oxide capacitance, depletion layer capacitance, admittance, capacitance , resistance due to unwanted lossy layer, lossy layer capacitance, , lossy layer resistance, series resistance, total series resistance, capacitance in strong accumulation, conductance in strong accumulation, measured capacitance, measured conductance. Corrected cacapacitance (C_C) and Corrected conductance (G_m):

$$C_c = \frac{(w^2 C_m C_E - G_m^2 - w^2 C_m^2)(G_m^2 + w^2 C_m^2)(C_E)}{(w^2 C_E^2)\left[G_m(1 - R_S' G_m) - w^2 R_S' C_m^2\right]^2 + (G_m^2 + w^2 C_m^2 - w^2 C_m C_E)^2}$$

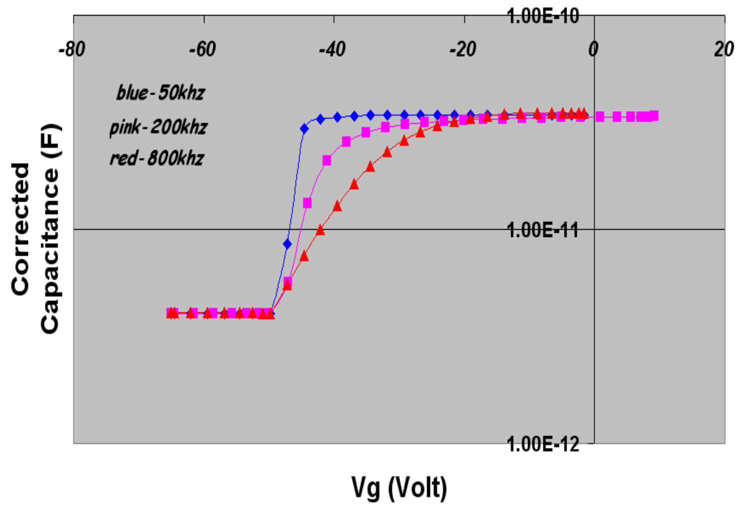
$$G_c = \frac{\left[G_m(1 - R_S' G_m) - w^2 R_S' C_m^2\right](G_m^2 + w^2 C_m^2)(w^2 C_E^2)}{(w^2 C_E^2)\left[G_m(1 - R_S' G_m) - w^2 R_S' C_m^2\right]^2 + (G_m^2 + w^2 C_m^2 - w^2 C_m C_E)^2}.$$

Simulation of irradiated device

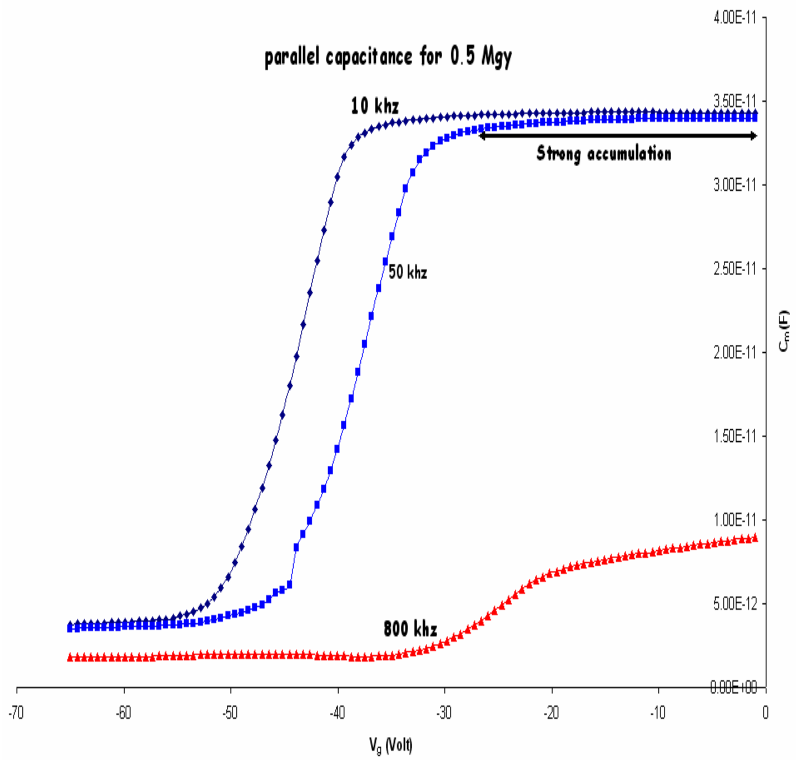
0.5 MGy →



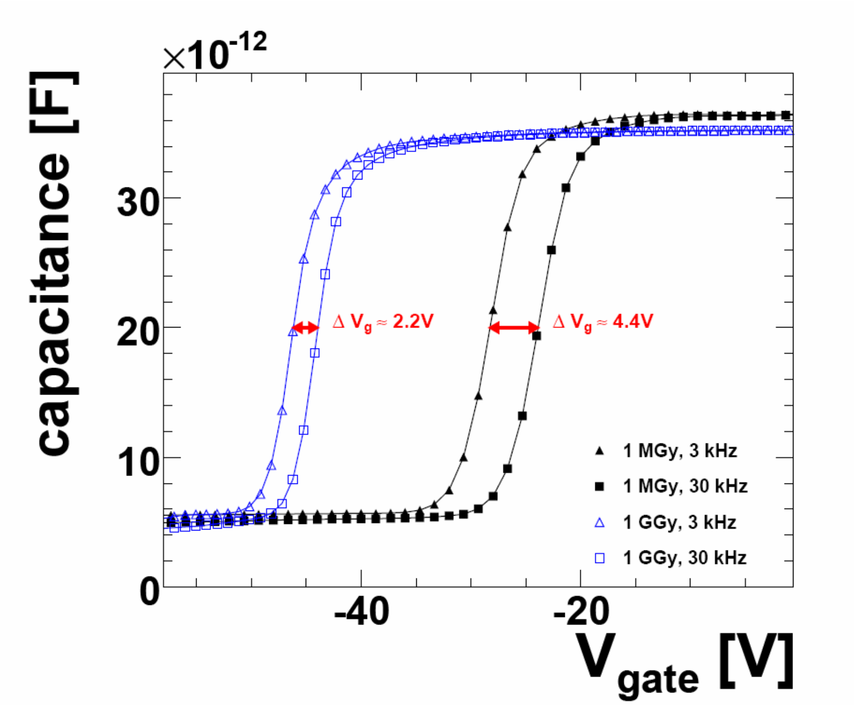
Corrected Capacitance for 0.5 MGY



Experimental C/V characterstics for 0.5 MGy



Experimental C/V characterstics for 1 MGy and 1 GGy



Exp. Result : E.F et al. IEEE NSS 2008

- Frequency dispersion effect in 0.5 MGy and highly irradiated device.