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Simulation of a Floating Gate Device in standard CMOS process for Dosimetry applications

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Outlook

- Introduction to Floating gate devices
- Use as radiation sensors for dosimetry applications
- Simulation results
- Conclusions

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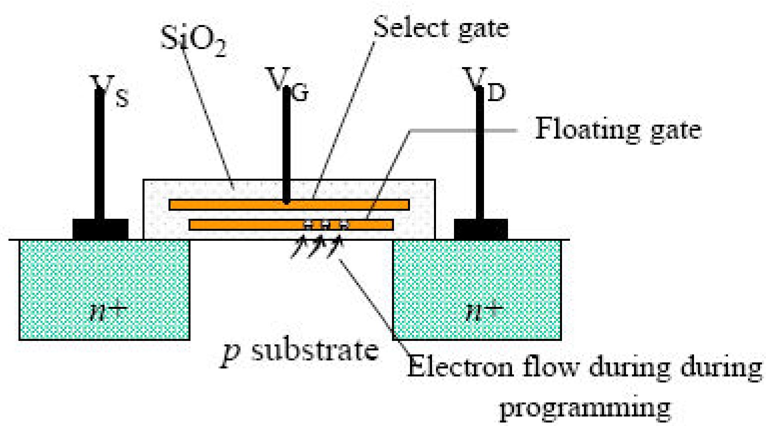
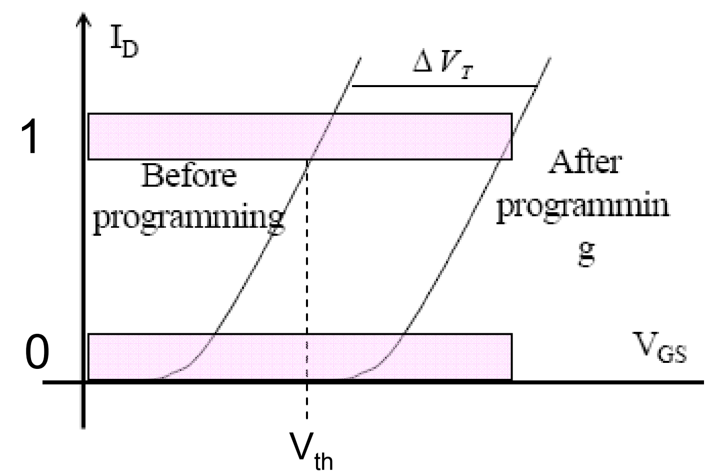
Introduction to Floating Gate Devices

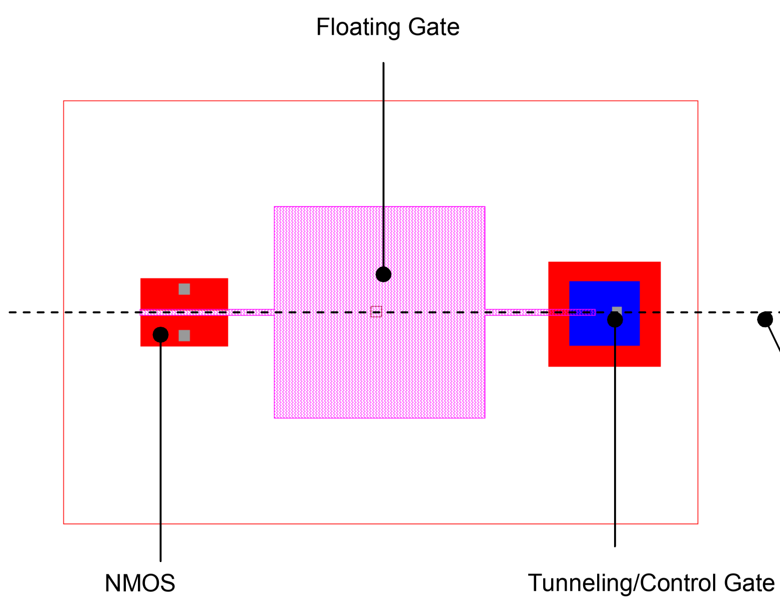
Dual poly floating gate devices have been in use for many years as NVM elements (EPROM, FLASH)

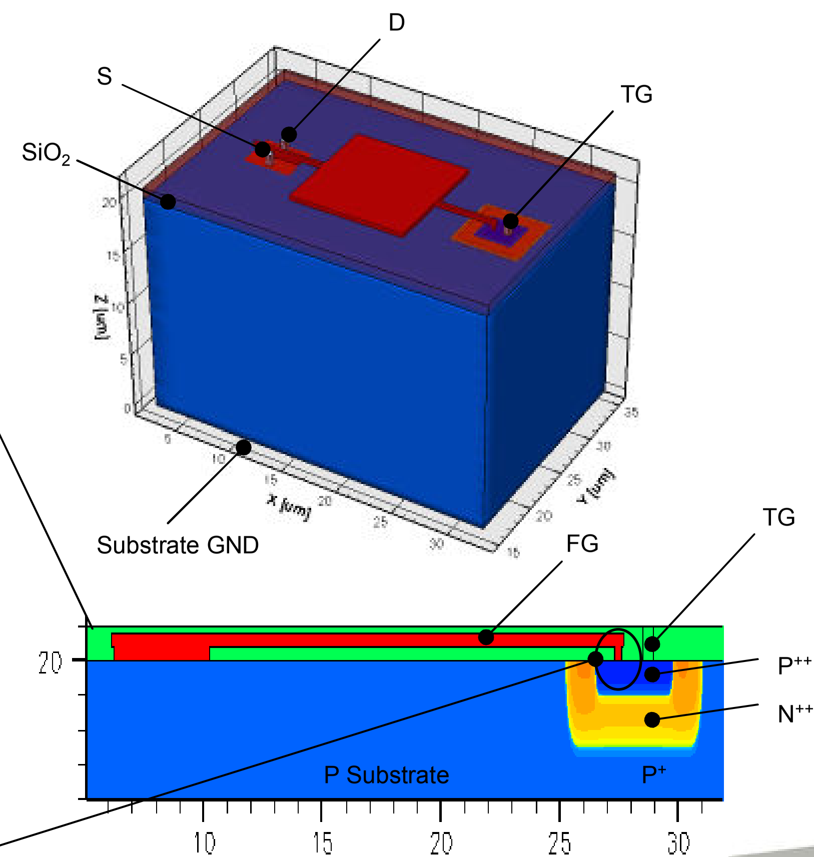




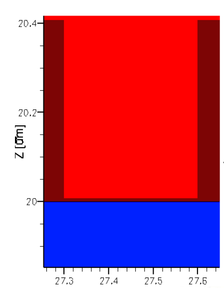
They have been proposed as radiation sensors for dosimetry or as basic blocks for analogue applications

Floating Gate Device

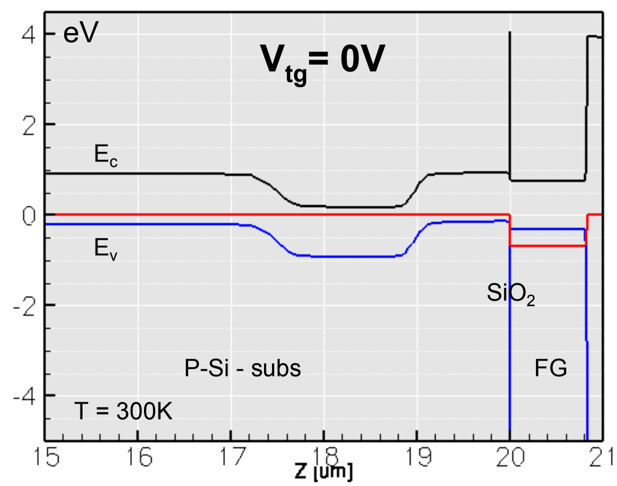


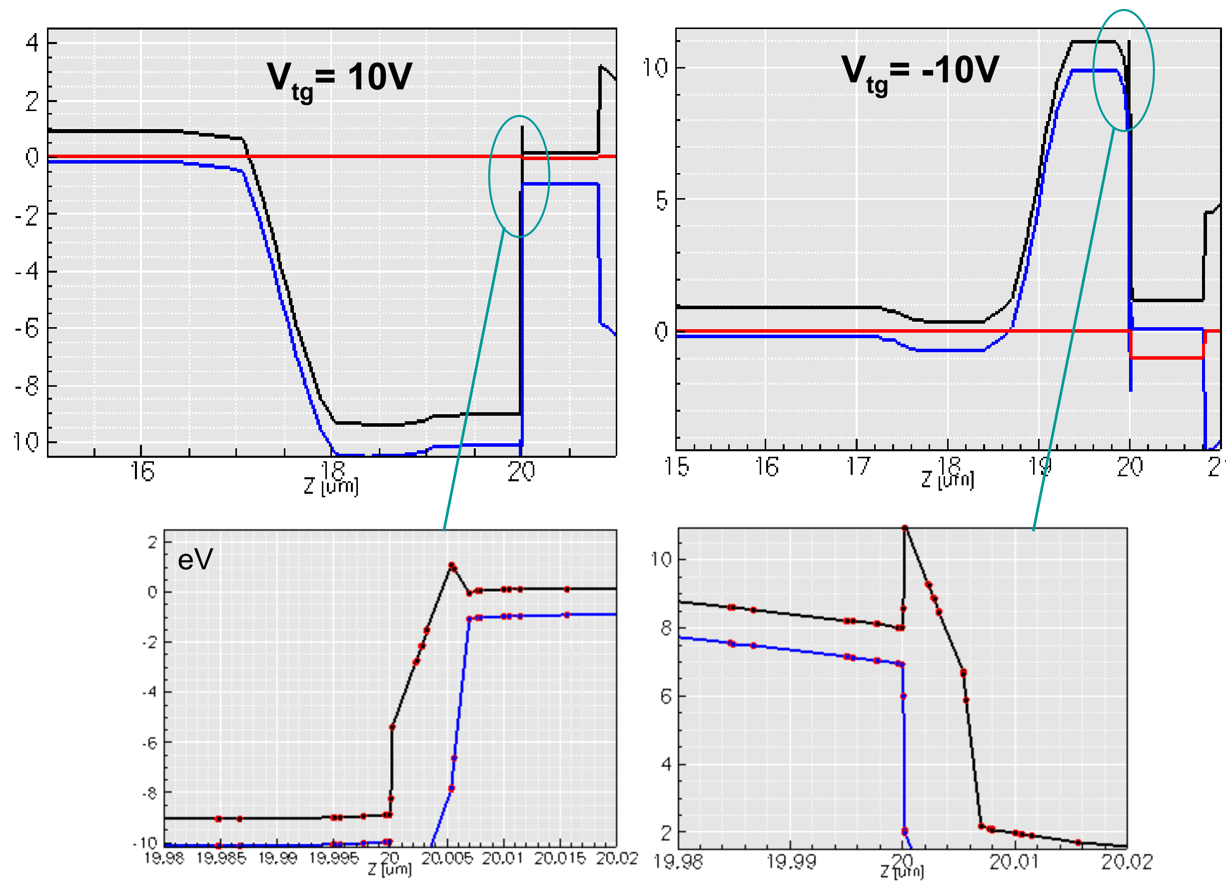


Radiation sensor from a standard single poly CMOS process used for NVM memory

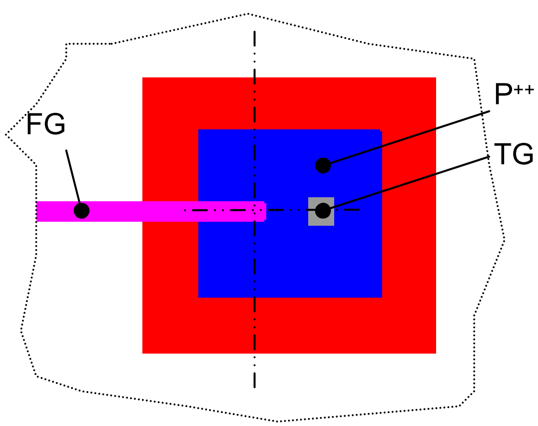


Device Programming





Tunneling through SiO_2 is enabled by applying a voltage bias to TG

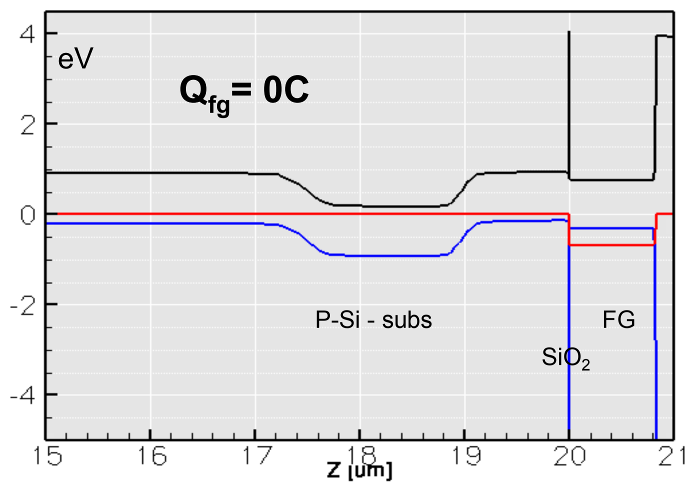


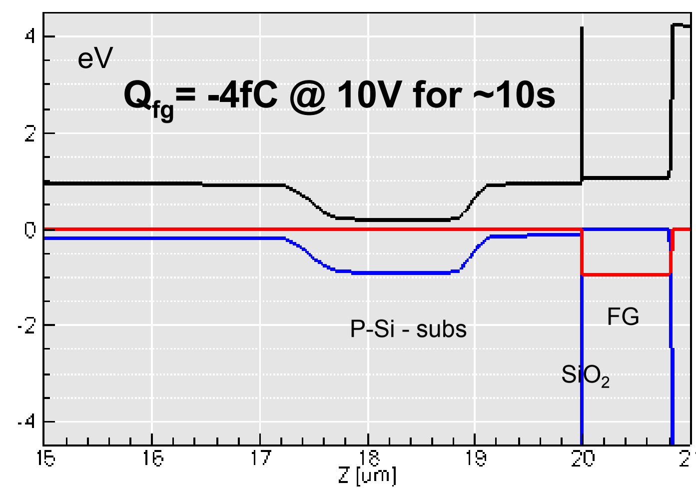
X section through tunneling area
(subs = 0V, D = S = 0V)

Band diagrams

Debye length ~ 5nm

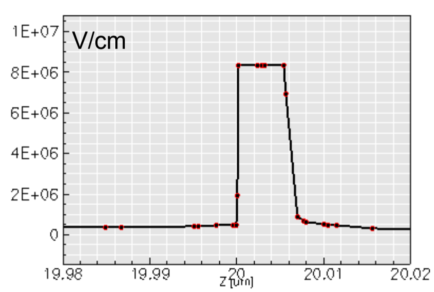
Device Programming

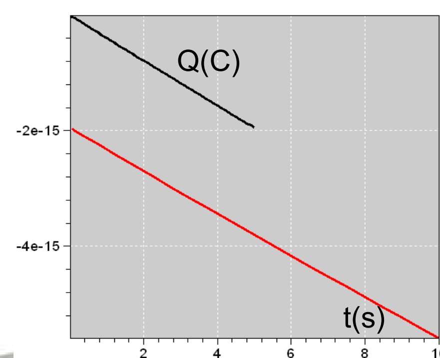




$$j_n = \frac{q m_c k}{2\pi^2 \hbar^3} \int_0^\infty Y(E) \left\{ T(0) \ln\left(\exp\left[\frac{E_{Fn}(0) - E_C(0) - E}{kT(0)} \right] + 1 \right) - T(d) \ln\left(\exp\left[\frac{E_{Fn}(d) - E_C(0) - E}{kT(d)} \right] + 1 \right) \right\} dE$$

Direct tunneling ≈ FN for F_{ox} > 6Mv/cm





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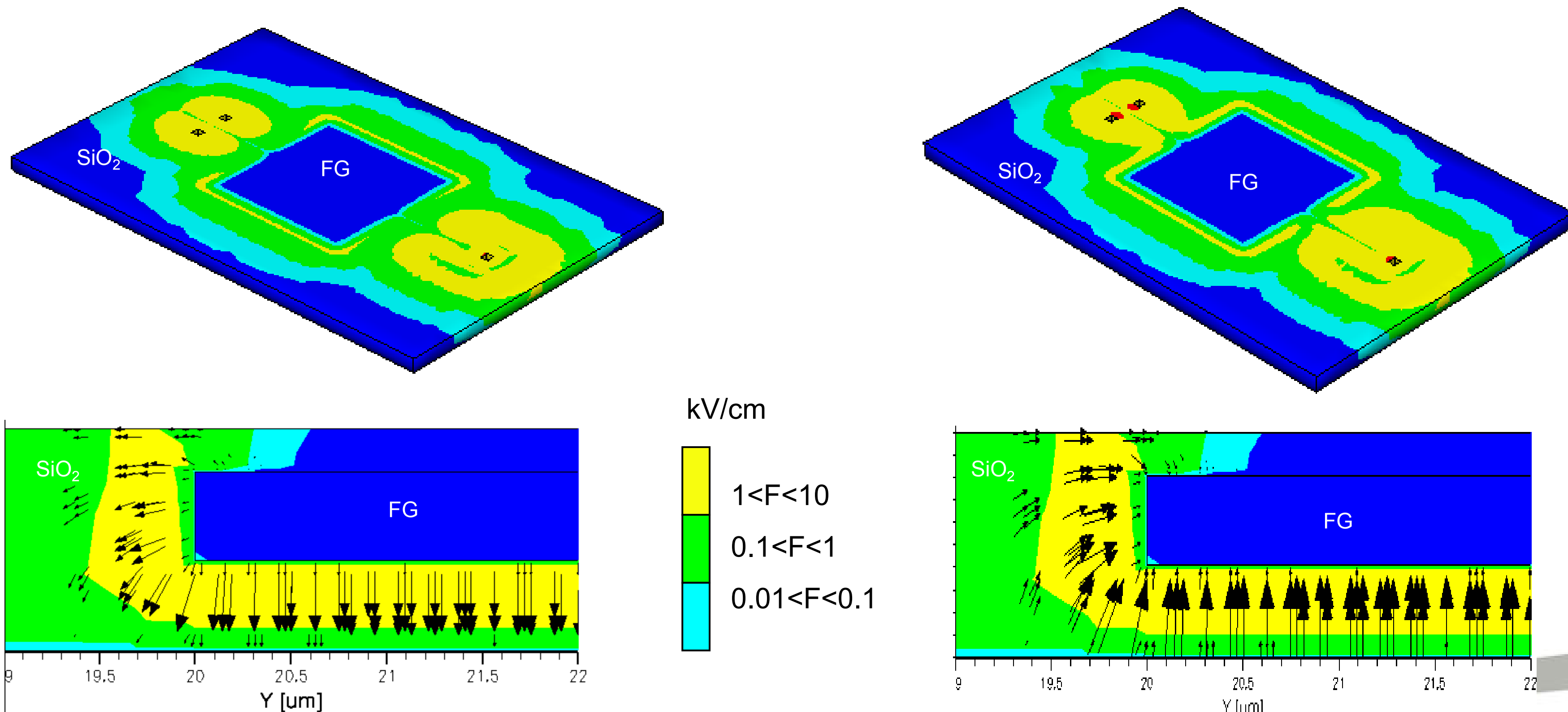
Electrical characteristics

Q_{fg}= 0C

Φ_{FG}= -0.228V

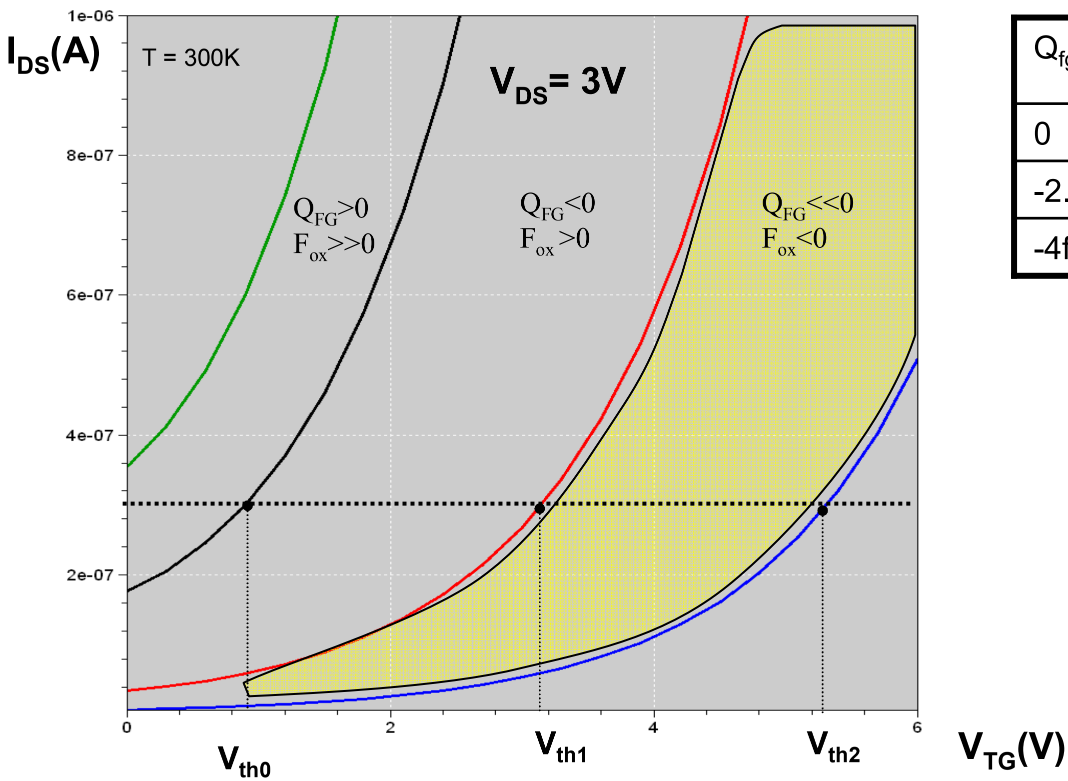
Q_{fg}= -4fC

Φ_{FG}= -0.506V



The intensity and direction of the SiO_2 electric field can be changed with Q stored in FG

Electrical characteristics



Q_{fg}	V_{th} (I_{ds}=0.3uA @ V_{ds} =3V)
0	0.898
-2.368fC	3.139
-4fC	5.307

The charge stored in the FG allows to change the threshold voltage in both directions

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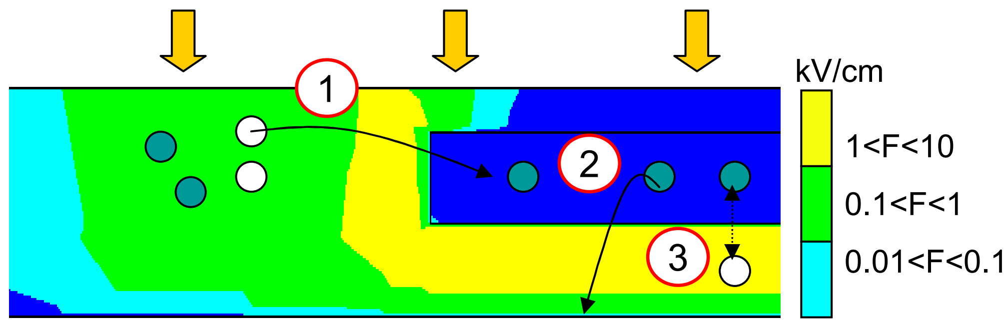
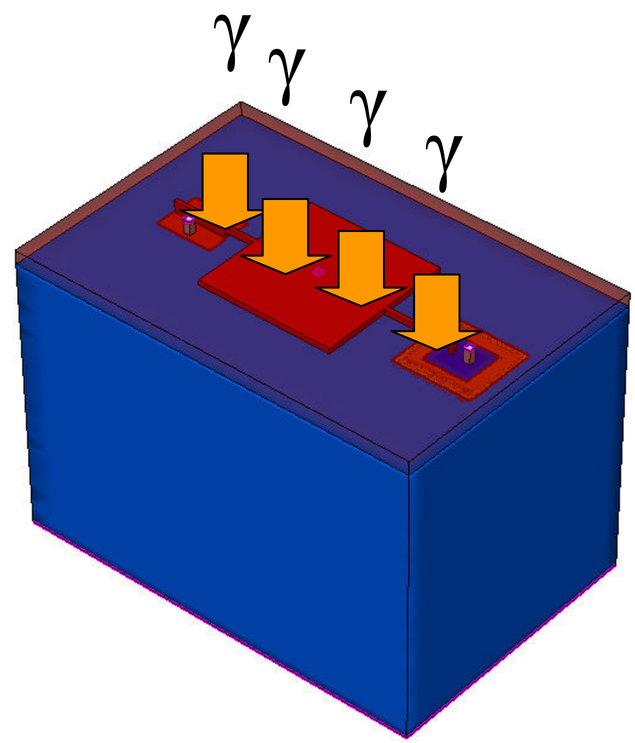
Radiation Detection

The deposited radiation in SiO_2 alters the internal electric field (F_{ox}): this affects the electrical characteristics of the device (V_{th})





Three main mechanisms of radiation sensing:

1. FG discharge via charge injection
2. FG discharge direct
3. Holes trapping (requires knowledge on SiO_2 processing)

FG discharge by holes collection from SiO_2, generated by gamma radiation

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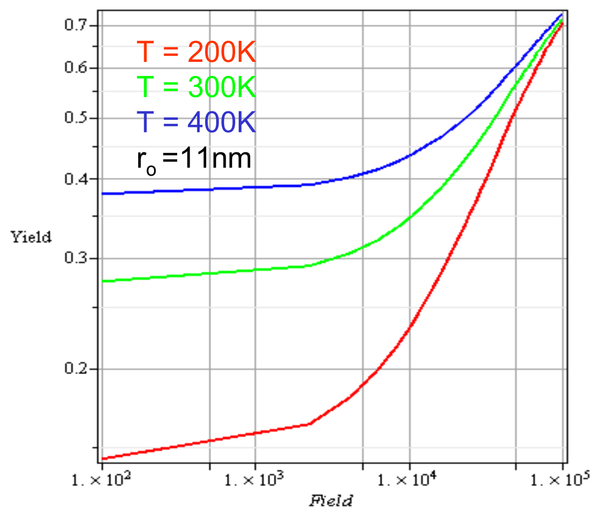
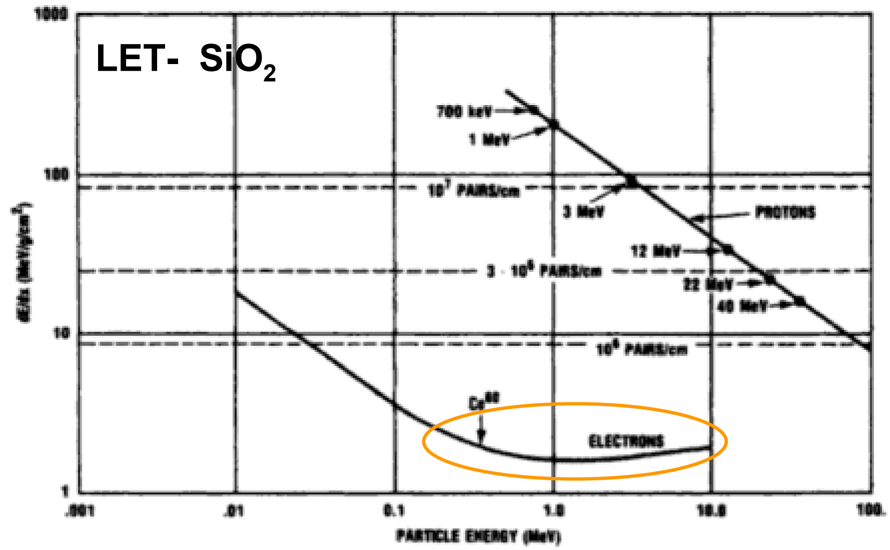
Radiation Detection





low LET particles: Onsager model

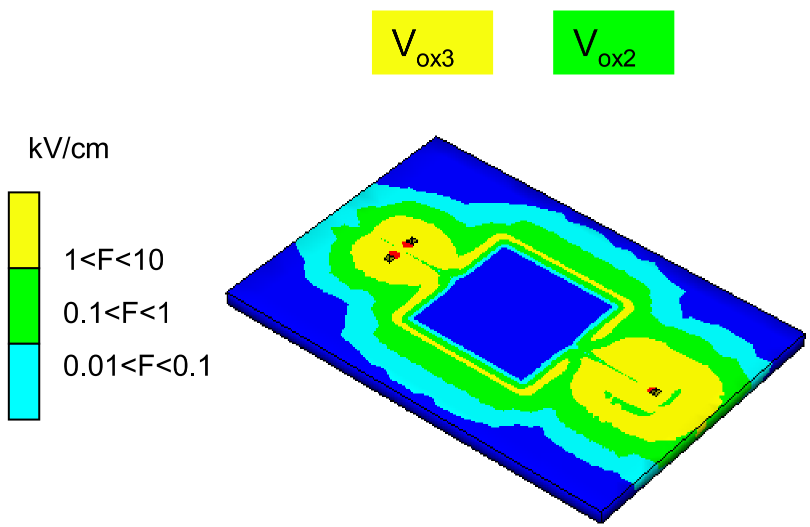
probability of an electron escaping recombination

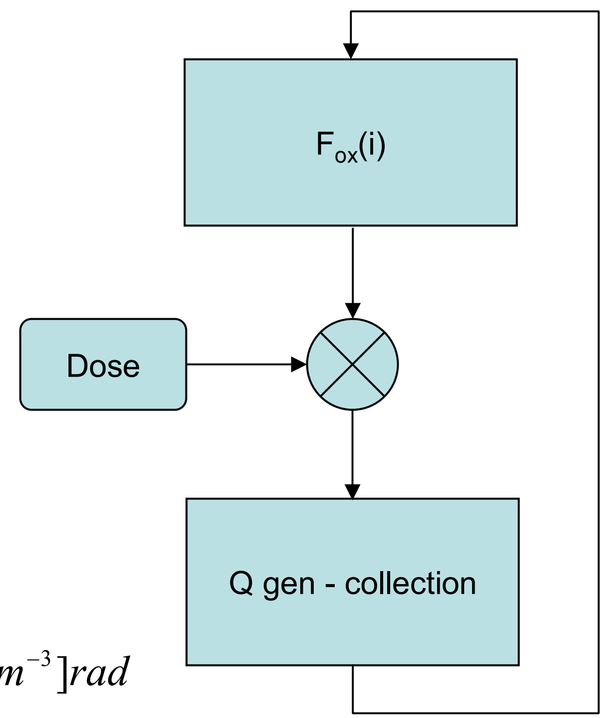
$$Y(F_{ox},T,r_o) = K^{-1}e^{(-A)}e^{(-K)}\sum_{m=0}^{\infty}\frac{A^m}{m!}\sum_{n=0}^{\infty}\sum_{l=m+n+1}^{\infty}\frac{K^l}{l!}$$

$$K = \frac{qF_{ox}r_o}{kT}$$

$$A = \frac{r_c}{r_o}, r_c = \frac{q^2}{4\pi\varepsilon_{SiO_2}kT}$$

Radiation Detection





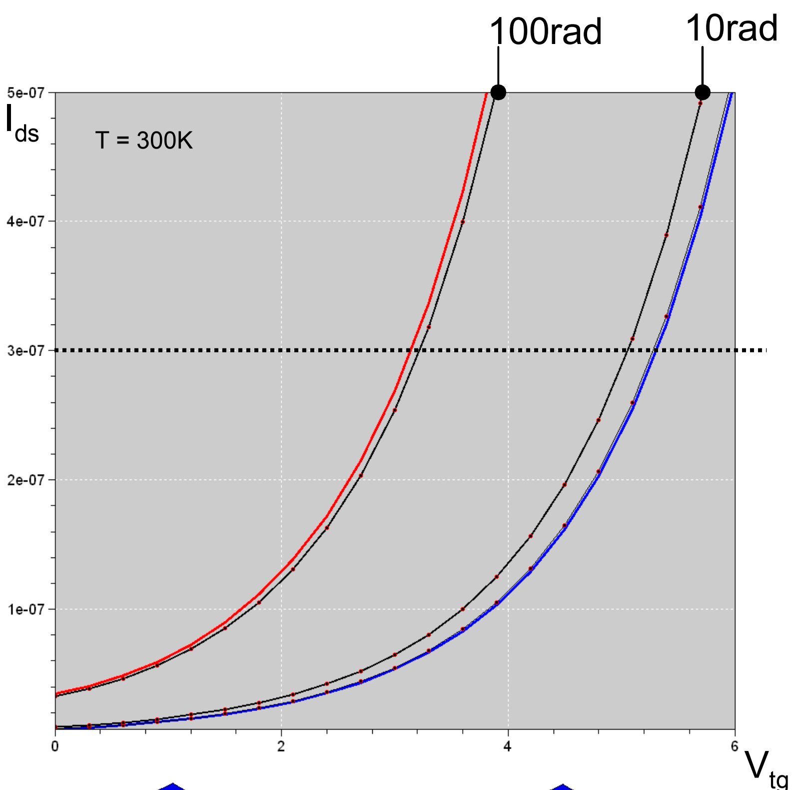
$$Q_{coll} = Q_{rad} \cdot \sum_i V_{oxi}(i) \cdot Y_{ox}(i) \quad ,i > 1$$

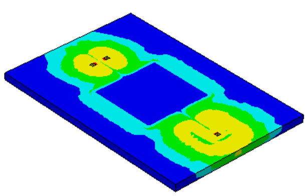
$$Q_{rad} = \frac{D \cdot \rho_{SiO_2}}{W_{SiO_2}} = \frac{6.24 \cdot 10^7 \left[MeV \cdot g^{-1}\right] \cdot 2.2 \left[g \cdot cm^{-3}\right]}{17 \left[eV\right]} \cong 8[\mu m^{-3}]rad$$

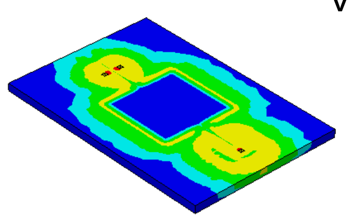
The collection of holes by FG generated in SiO_2 is a function of F_{ox}

The F_{ox} is updated after new charge collection to estimate effect of decreasing FG charge

Radiation Detection

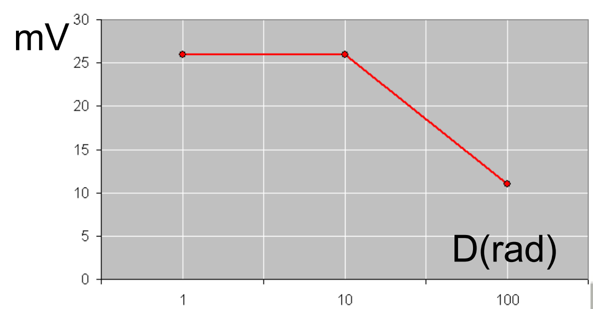






D	Vth @ Ids=0.3μA
0	5.307
1rad	5.281
10rad	5.056
100rad	3.214

D	Sensitivity (ΔVth/rad)@ Vds=3V
0	26mV
10rad	26mV
100rad	11mV



The sensitivity decreases as the FG discharges

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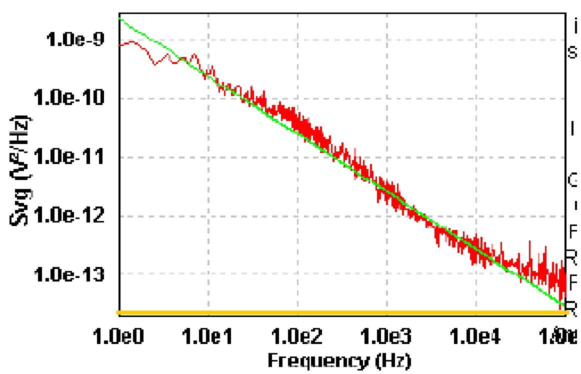
Noise analysis

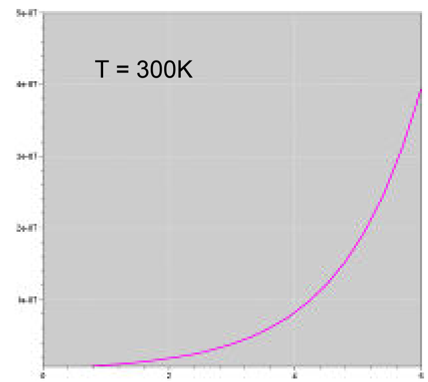
The gate referred noise of the device has estimated spectral density:

$$v^2{}_{noise} = 4kT\frac{2}{3}\frac{1}{g_m} + \frac{K_f}{WL}\frac{1}{f^{\alpha}} \cong 4.8e-14 + \frac{2.5e-9}{f^{0.8}} \quad \Rightarrow \quad \int_{1e-3}^{10} v_{noise}\,df \cong 330\mu Vrms$$



Typ. Flicker noise spectrum

W/L = 10/0.18



$g_m(V_{th}) \approx 2.3e-7A/V$

D	Sensitivity (ΔVth/rad)@ Vds=3V, T = 300K)	Max resolution (Rad)
0	26mV	0.0384
10rad	26mV	0.0384
100rad	11mV	0.091

Assuming a minimum readout time of 10 readings/sec over a period of 1hr and 3 times the RMS value as minimum detectable V_{th} change gives the resolution in rad of the device

Conclusions

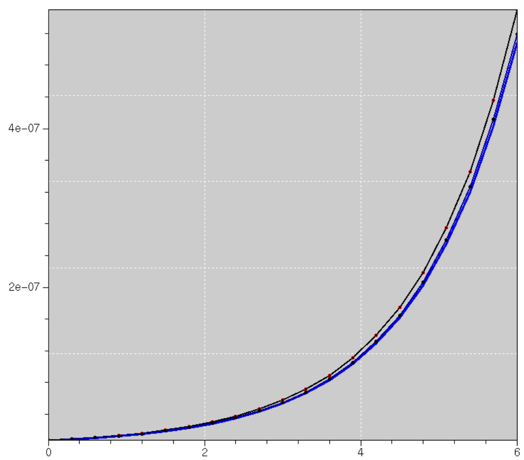
The device simulations results suggest the use of this technology for radiation dosimetry
The sensitivity is estimated to be << 1rad for 1 to 10Mev photons
The dynamic range will also depend on the device layout
The technology is CMOS standard and allows the integration on the same substrate of the readout electronics

Planned activities:

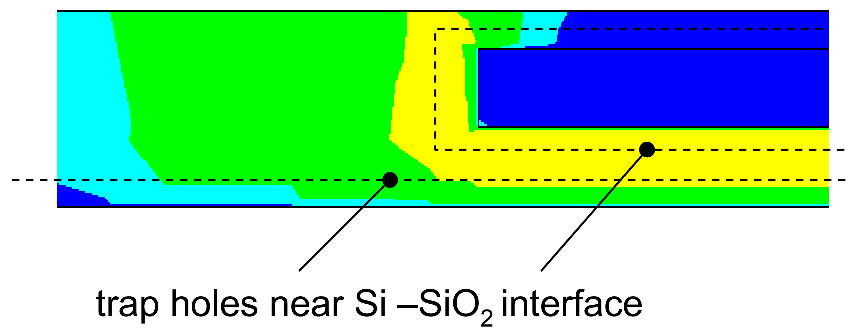
Further studies of charge collection mechanisms and transport in the SiO_2
Negotiation with foundry to obtain test devices
Grant application for funding for an in vivo dosimetry project

Backup slides

The hole transport in SiO_2: hopping and trap assisted transport produce dispersive transport



Simulation with Q_{ox} =1e12cm^{-3} ΔV_{th} = 101mV
Assuming holes trapped uniformly in SiO_2



At low doses, the hole trapping will take place mostly near the interfaces SiO_2/Si:
need more information on SiO_2 processing to estimate hole trap density and levels

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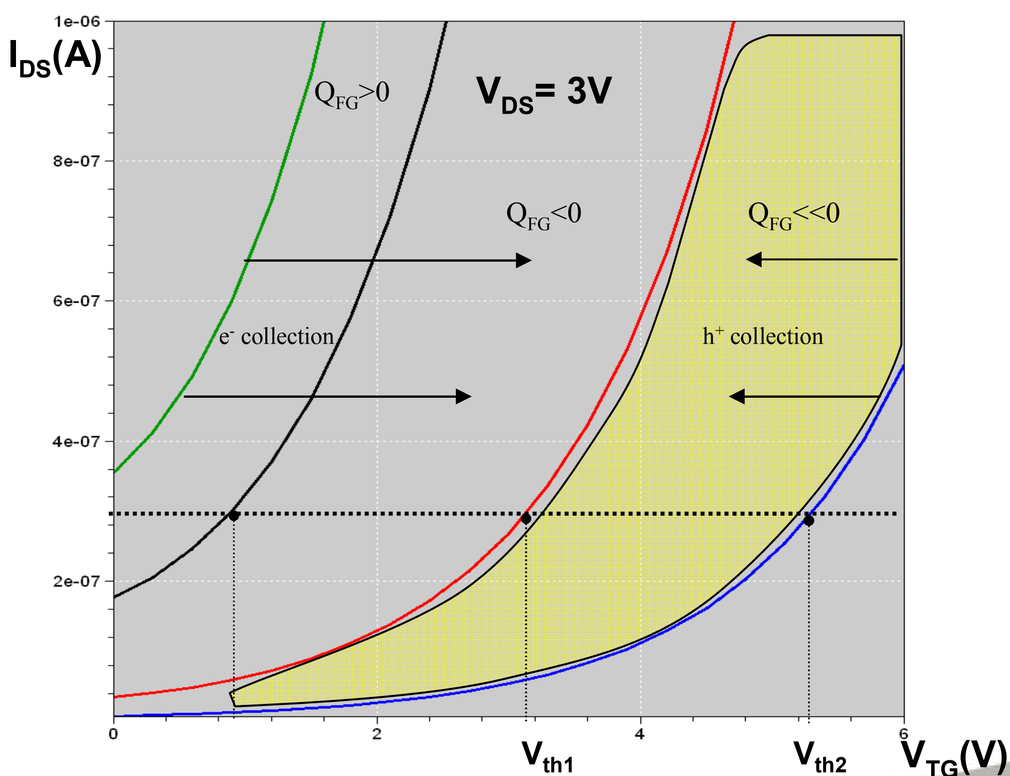
Backup slides

In principle electron could be collected instead of holes: this would *increase* the threshold voltage



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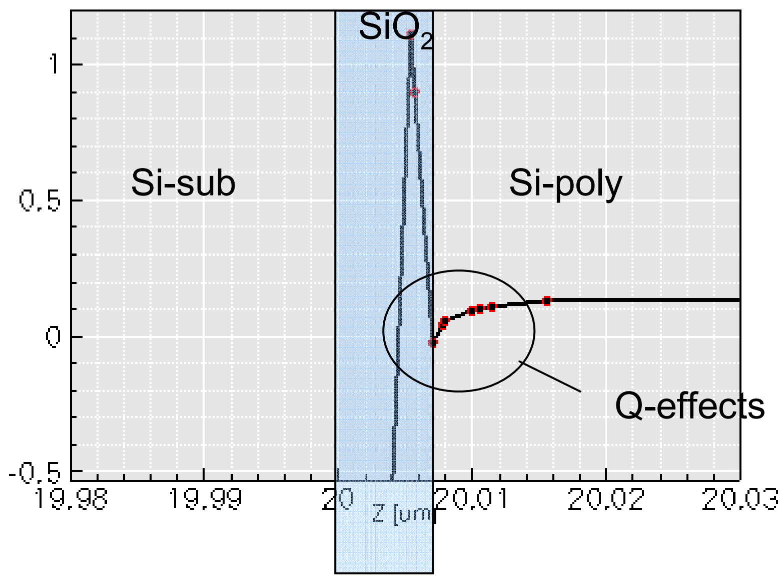
Backup slides

Depletion (enhancement) effects at the boundaries are taken into account
Quantization effects due to band bending to be studied (but unlikely to be so relevant for this application)



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