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BSIM4 Research and Updates

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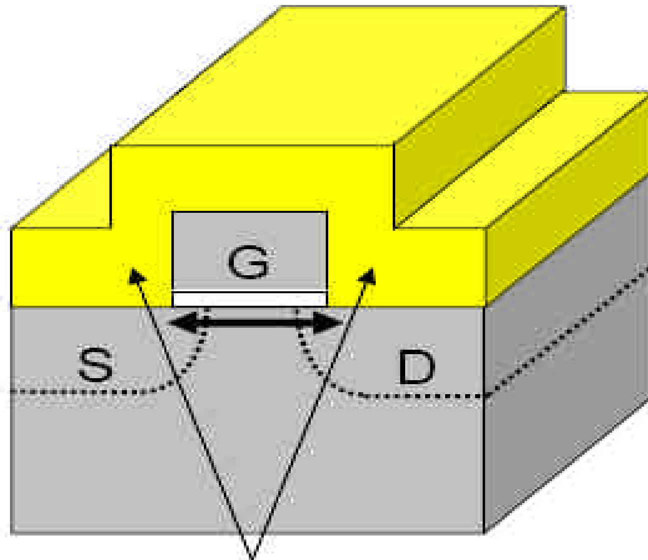
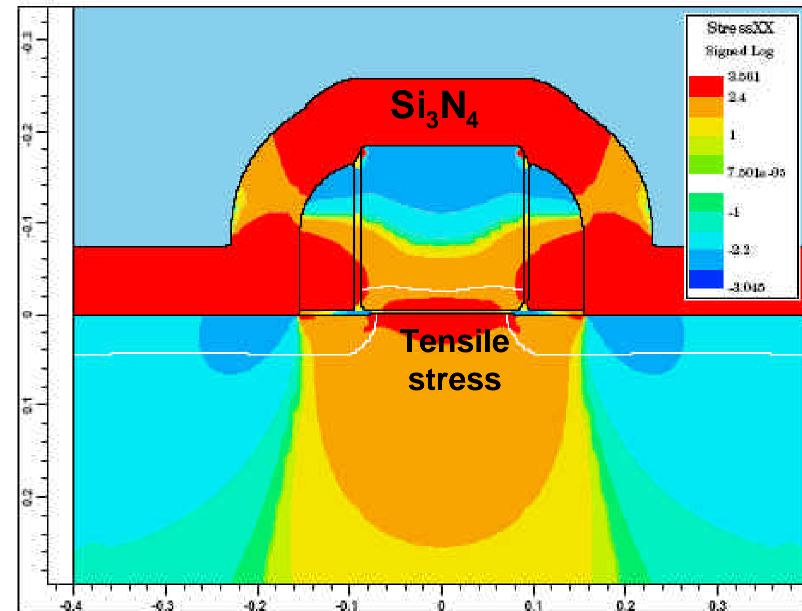
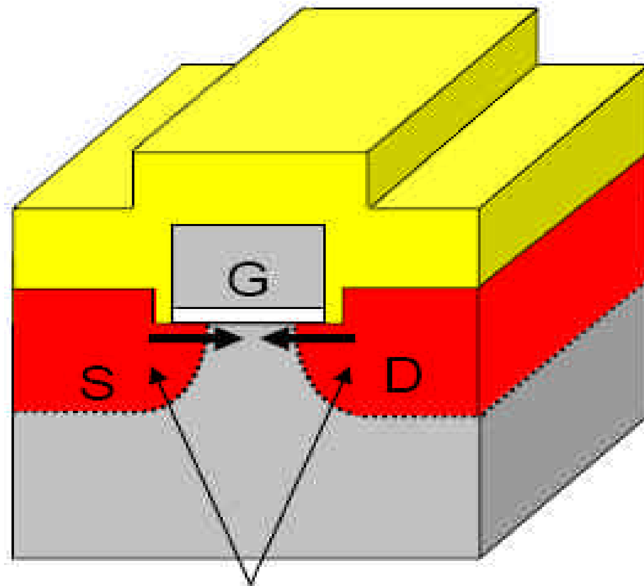
Strain Silicon Investigation[1]

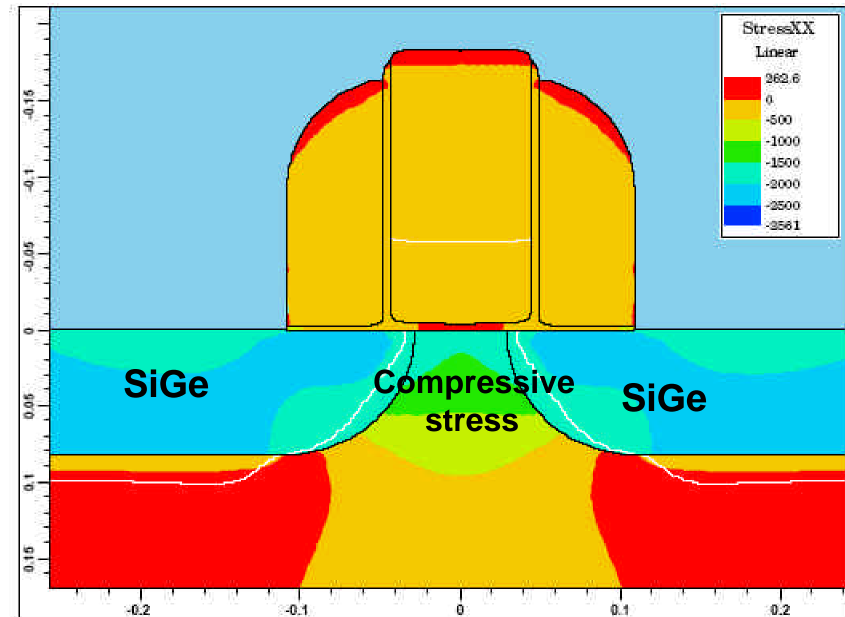




- **Device capped with etch-stop layer with high etching selectivity**
  [T.Ghani et al., IEDM, pp.8-10, (2003)]
- **Mechanical stress of the capping layer gets transferred to the device channel.**
- **Favor of NMOS mobility improvement**

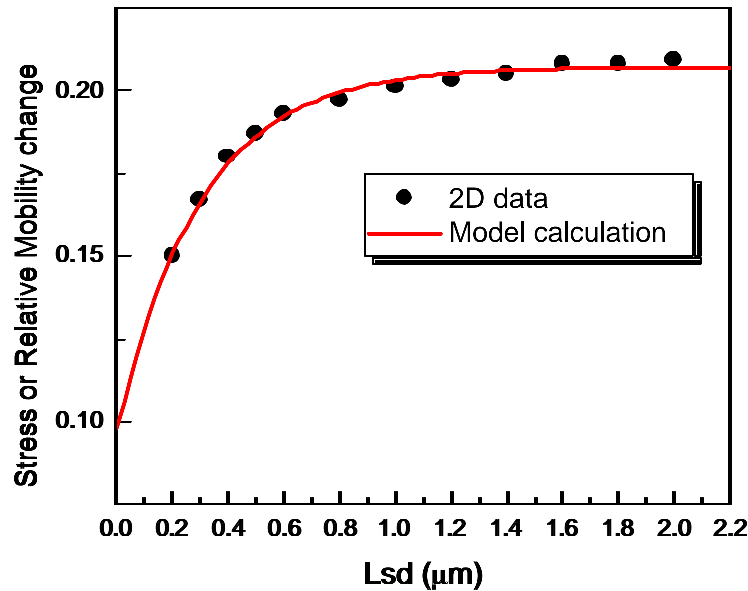
Strain Silicon Investigation[2]

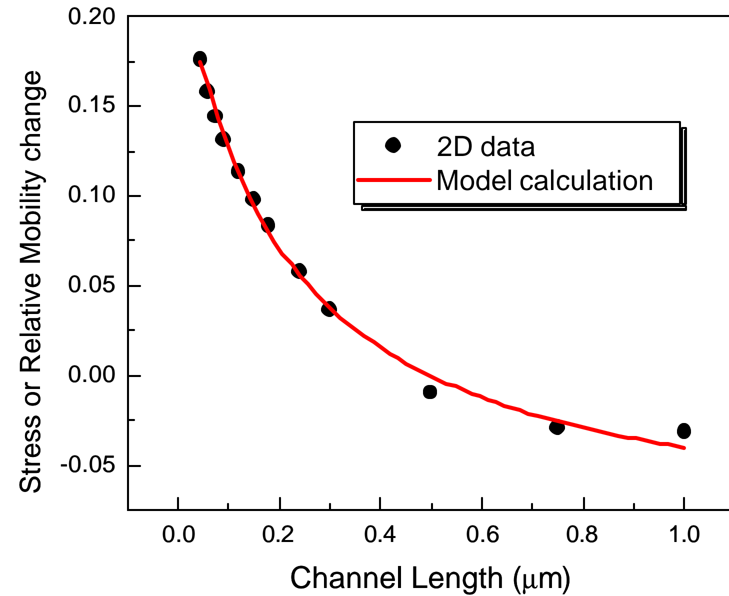




- **Uniaxial compressive strain created by SiGe S/D.**
- **More than 50% improvement in hole mobility reported.**
  [T.Ghani et al., IEDM, pp.8-10, (2003)]
- **Promises to be strong candidate for PMOS mobility improvement.**

Strain Silicon Investigation[3]





$$\rho_{\mu_{eff}} \propto \left(1 - \exp\left(-\frac{Lsd}{l_{es}}\right)\right) \qquad \rho_{\mu_{eff}} \propto \left(1 + \frac{PL}{L + \Delta L}\right)$$

$$\rho_{\mu_{eff}} = \Delta\mu_{eff} / \mu_{effo} = (\mu_{eff} - \mu_{effo}) / \mu_{effo} = \frac{\mu_{eff}}{\mu_{effo}} - 1$$

$$\propto \left(1 - \exp\left(-\frac{Lsd}{l_{es}}\right)\right) \cdot \left(1 + \frac{PL}{L + \Delta L}\right)$$ **(relative mobility change due to stress)**

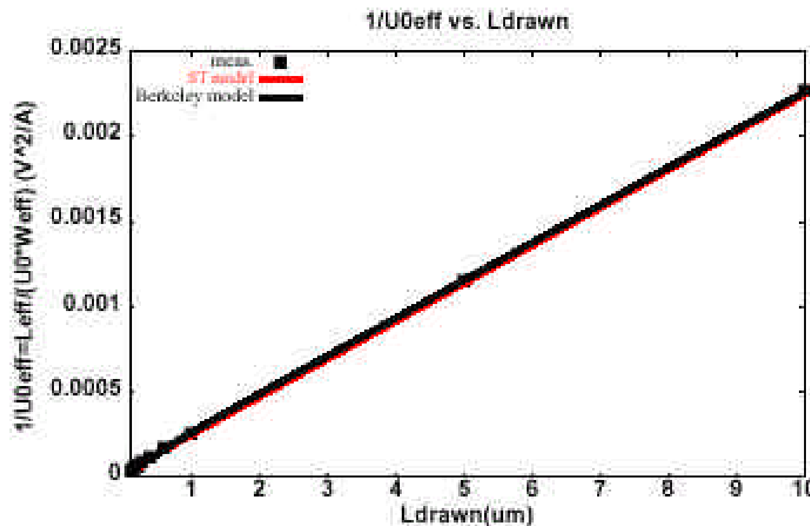
Mobility Channel Length Dependence

- Stress Effect Induced Mobility Channel Length Dependence

$$\rho_{\mu eff} = \frac{ku0}{Kstress_u0} \cdot (Inv_sa + Inv_sb)$$

$$Inv_sa = \frac{1}{SA + 0.5 \cdot L_{drawn}} \qquad Inv_sb = \frac{1}{SB + 0.5 \cdot L_{drawn}}$$

$$Kstress_u0 = \left(1 + \frac{LKU0}{(L_{drawn} + XL)^{LLODKU0}} + \frac{WKU0}{(W_{drawn} + XW + WLOD)^{WLODKU0}} + \frac{PKU0}{(L_{drawn} + XL)^{LLODKU0} \cdot (W_{drawn} + XW + WLOD)^{WLODKU0}}\right) \times \left(1 + TKU0 \cdot \left(\frac{Temperature}{TNOM} - 1\right)\right)$$

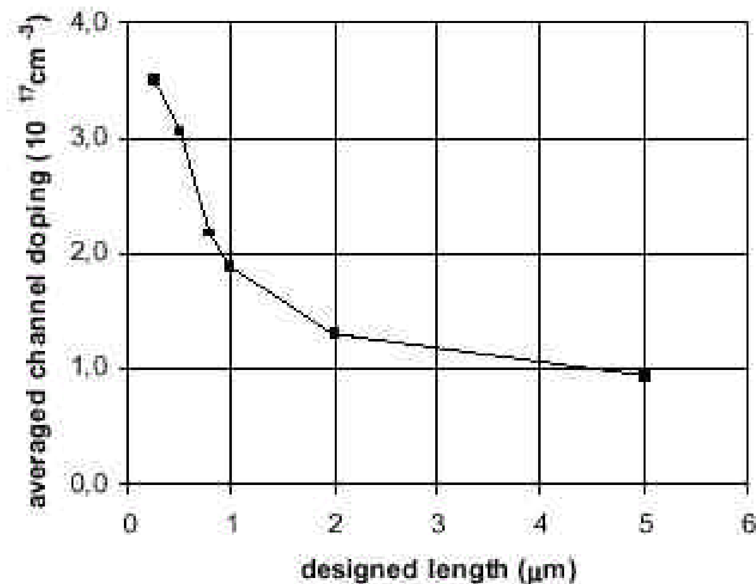


❑ BSIM4.3-2002 model and ST models are equivalent for L-scaling of the mobility.

Mobility Channel Length Dependence

- Halo Doping Induced Mobility Channel Length Dependence

  Halo doping ⇒ Effective Doping Neff(L) ⇒μ_{eff}(L)



Peter Klein and Steffen Chladek, "A New Mobility Model for Pocket Implanted Quarter Micron n-MOSFETs and Below", 2001, Infineon Technologies

$$\mu_{eff} \approx \frac{\nu_{eff}}{1 + \frac{UP}{L_{eff}}}$$

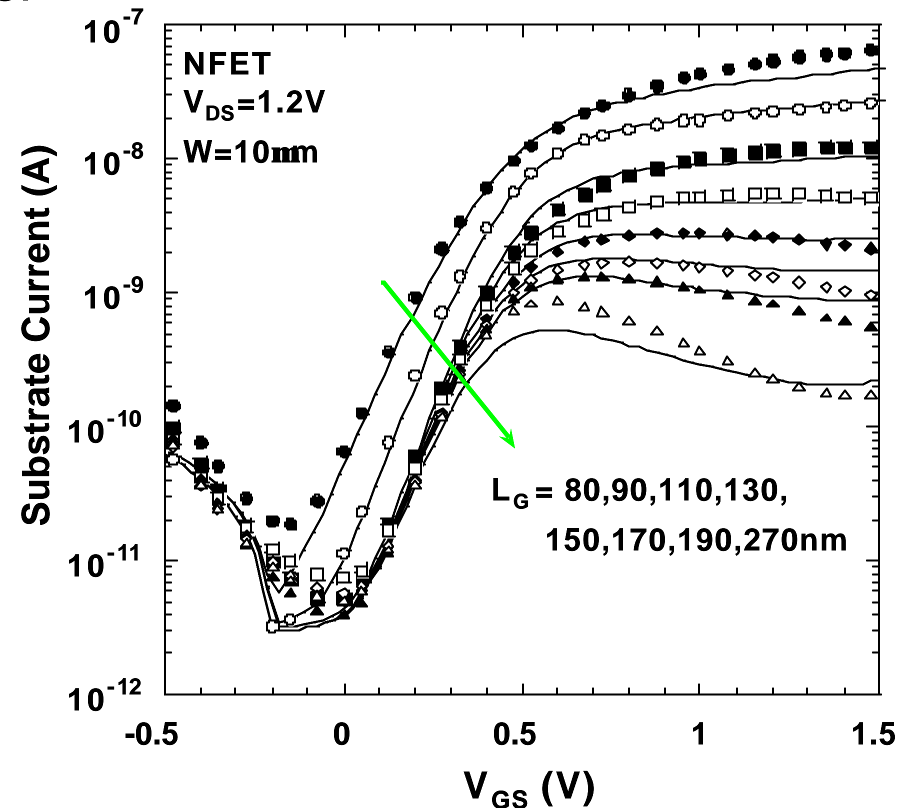
New Features for BSIM4 Enhancement

- Improved Impact Ionization Model

$$I_{II}/I_D \sim exp\left(\frac{V_D}{\beta_0 + \beta_1 V_D + \beta_2 V_D^2}\right)$$

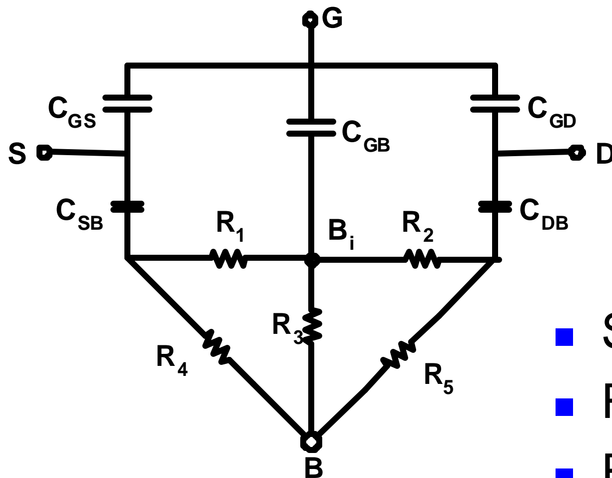
$$\sim \begin{cases} exp(V_D/\beta_0) & \text{in the low } V_D \\ exp(1/\beta_2 V_D) & \text{in the high } V_D \end{cases}$$

- **Thermally-assisted Impact Ionization besides normal II mechanism**



New Features for BSIM4 Enhancement

- Scalable Substrate Resistance Model



$$R_X = R_{X_HORI} \parallel R_{X_VERT}$$

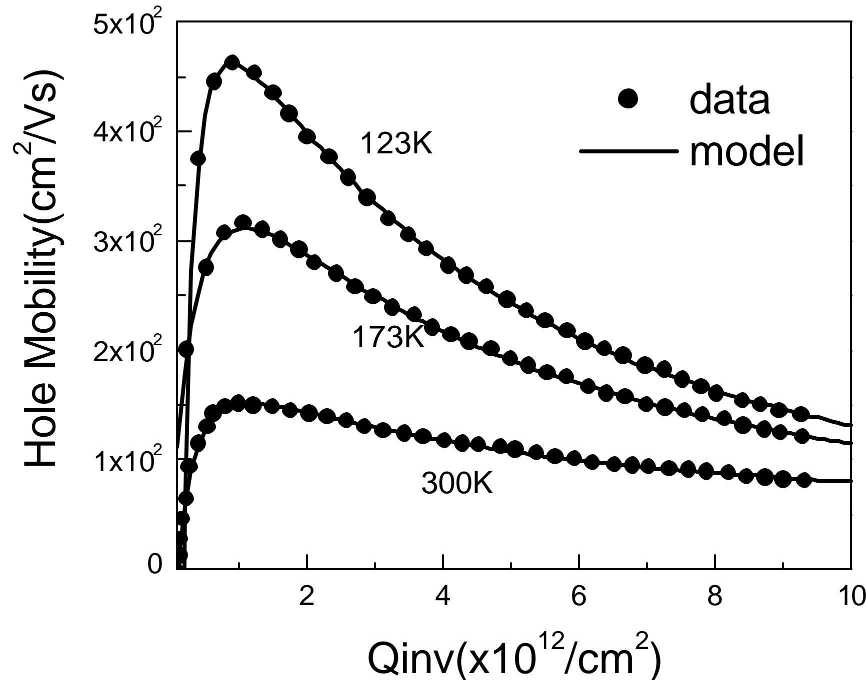
where $$R_{X_H(V)} = R_0 L^a W^{\beta} NF^{?}$$

- Symmetry consideration reduces parameters from 40 to 26.
- R1, R2 need not differentiate contact arrangements.
- R4 and R5 expected to have similar scaling laws.

New Features for BSIM4 Enhancement

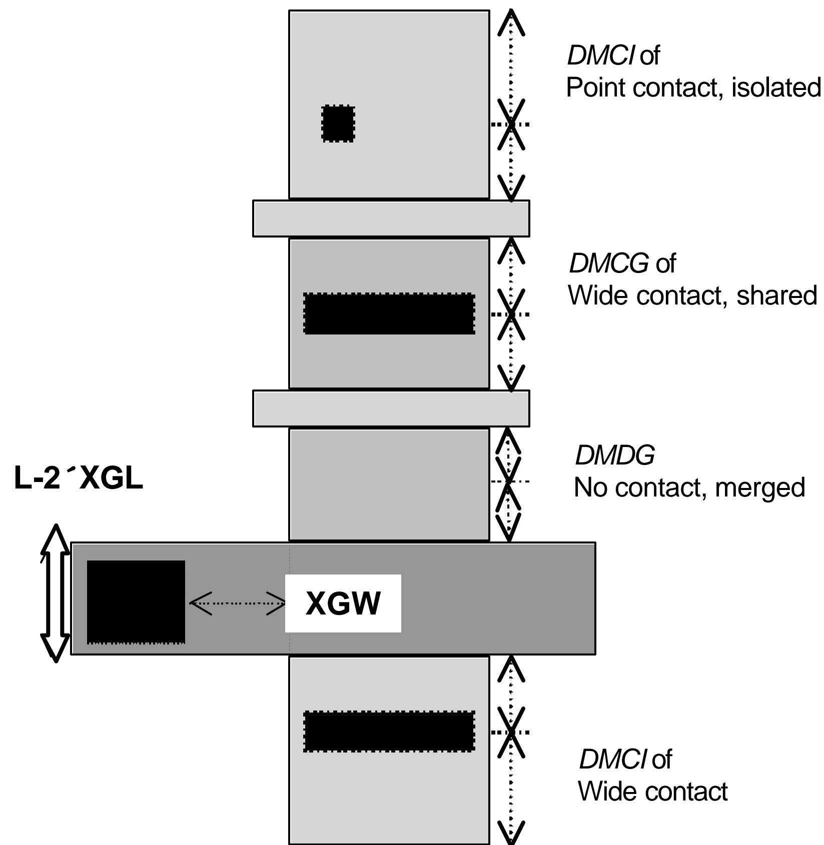
- Mobility Coulomb Scattering Model

$$\mu_{eff} = \frac{U0}{1 + \left(UA + UC V_{bseff}\right)\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right) + UB\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right)^2 + UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2V_{th}}\right)}$$



New Features for BSIM4 Enhancement

- XGW, NGCON Instance Parameters



New Features for BSIM4 Enhancement

- TempMod=2:

  Basic temperature equation the same as TempMod=1

  Temperature modeling of DITS

  Temperature modeling for gate current (Temp replaced by Tnom)

  voff

$$VOFF = VOFF + VOFFT \cdot \left(\frac{T}{TNOM} - 1 \right)$$

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BSIM5 R2R Circuit Test