



Guidelines for MOSFET Device Optimization accounting for L-dependent Mobility Degradation

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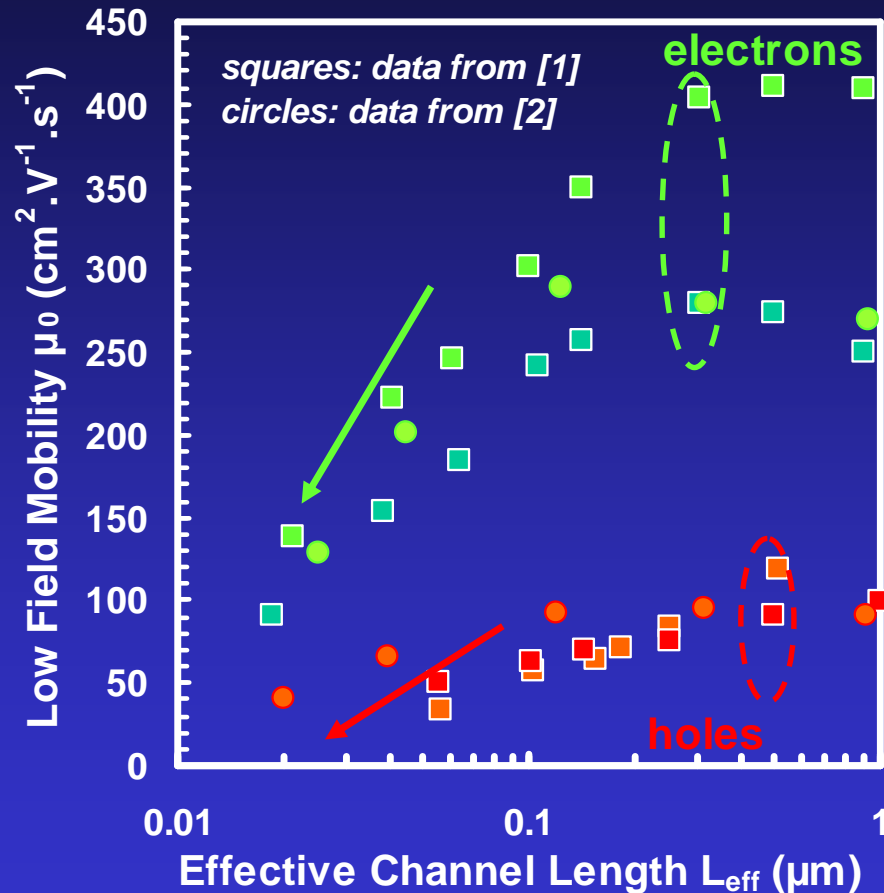
Outline

- **Introduction**
- **Methodology used in this work**
 - Low field apparent mobility
 - μ -degradation modeling
- **Experimental results**
 - Impact of technological modules
- **Guidelines for transport enhancement**
 - How close to ballistic ?
 - Benchmark of studied technological modules
- **Conclusion**

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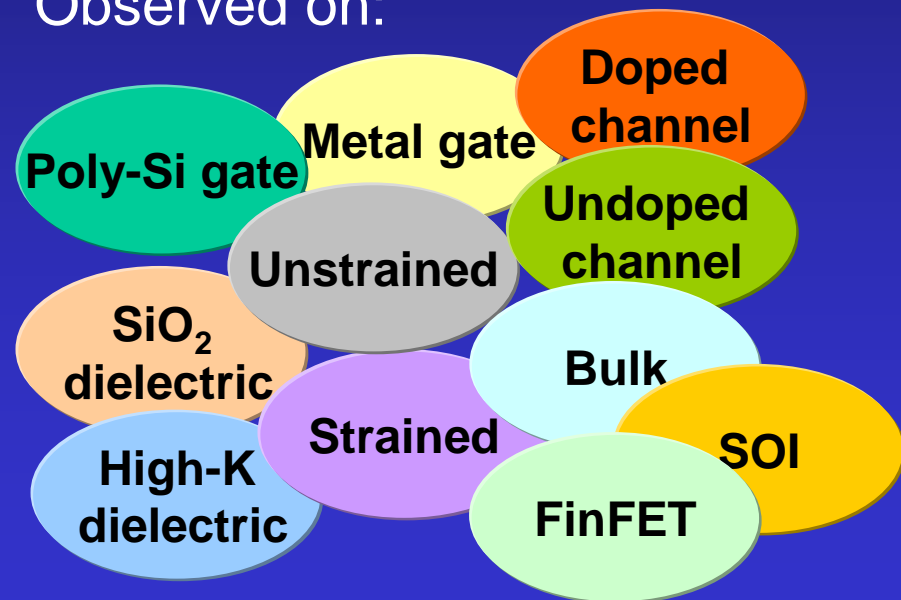
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Mobility crisis in highly scaled devices



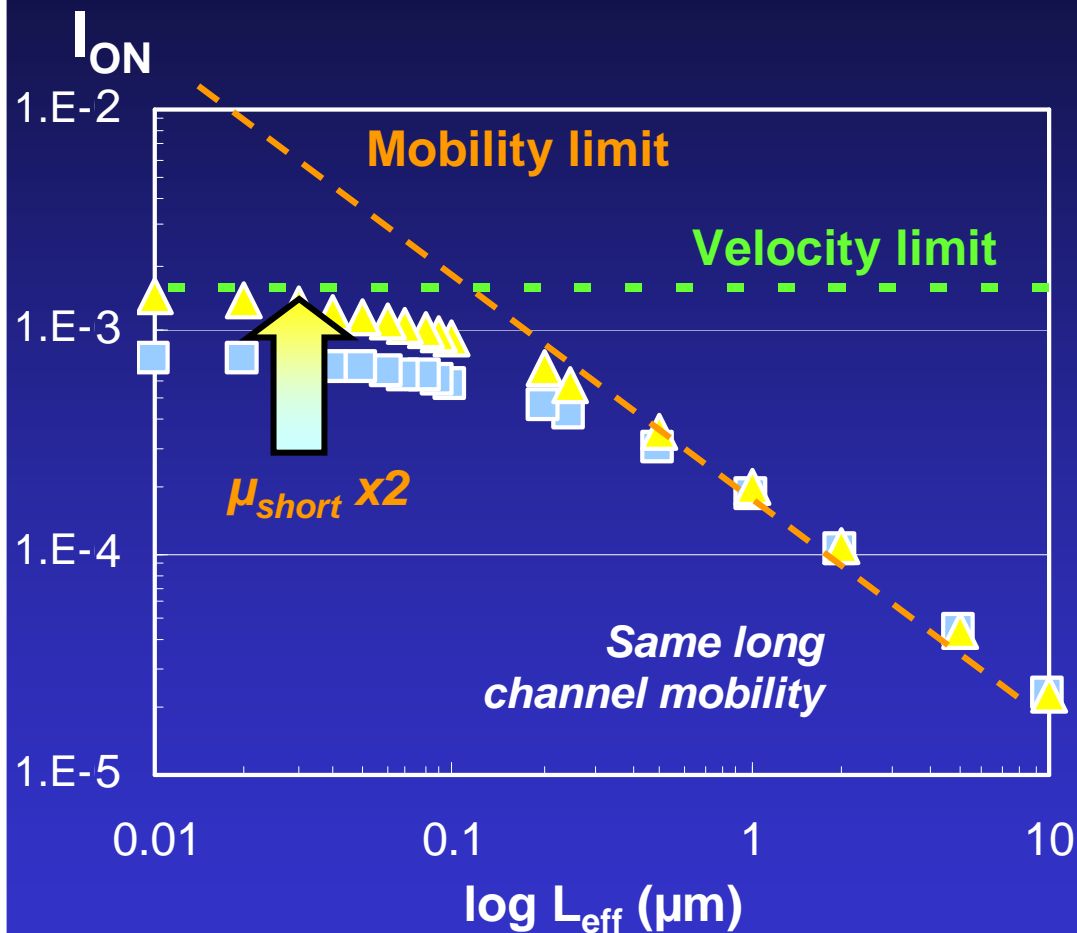
[2]: F.Andrieu et al., VLSI 05 [2]: A.Cros et al., IEDM 06

- Experimental evidence of carriers' mobility diminution as L_g is scaling down [K.M.Cao IEDM 99, K.Rim IEDM 02, M.Zilli EDL 07, Ramos ESSDERC 06]
- Observed on:



G.Bidal et al. , SNW 2009, June 2009, Kyoto (Japan)

Motivation



- If mobility is high enough and only in this case, the mobility term $1/(\mu_0 E_{lateral})$ can become negligible and the transport will be mainly driven by the limiting velocity

$$I_{dsat} = WC_{ox} V_{gt} \times \frac{1}{1/v_{lim} + 1/(\mu_0 E_{lateral})}$$

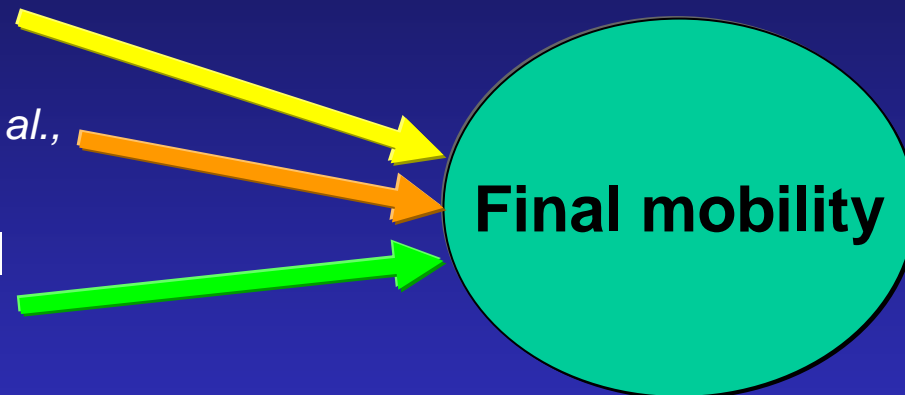
From T.Skotnicki et al., IEEE TED'08



- Any mobility enhancement will get us closer to the limiting velocity

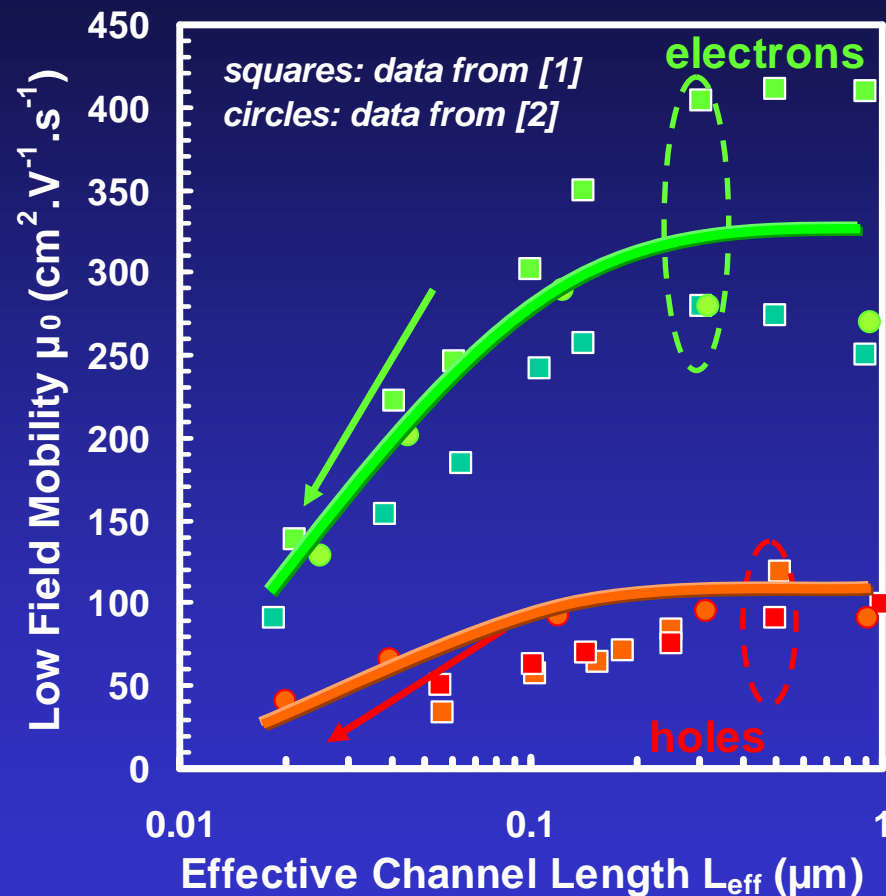
Purpose of this work

- Many possible explanations...
 - long range CS from S/D [M.Cassé et al., VLSI 2008]
 - CS from the high-K [V.Barral et al., SNW 2008]
 - neutral defects due to S/D I/I [A.Cros et al., IEDM 2006]
 - etc.
- ... that may be mixed !



- Purpose of this work is not to diagnose the mechanisms of this mobility degradation, but to identify key technological modules that may help to reach a higher short channel mobility

How to ?



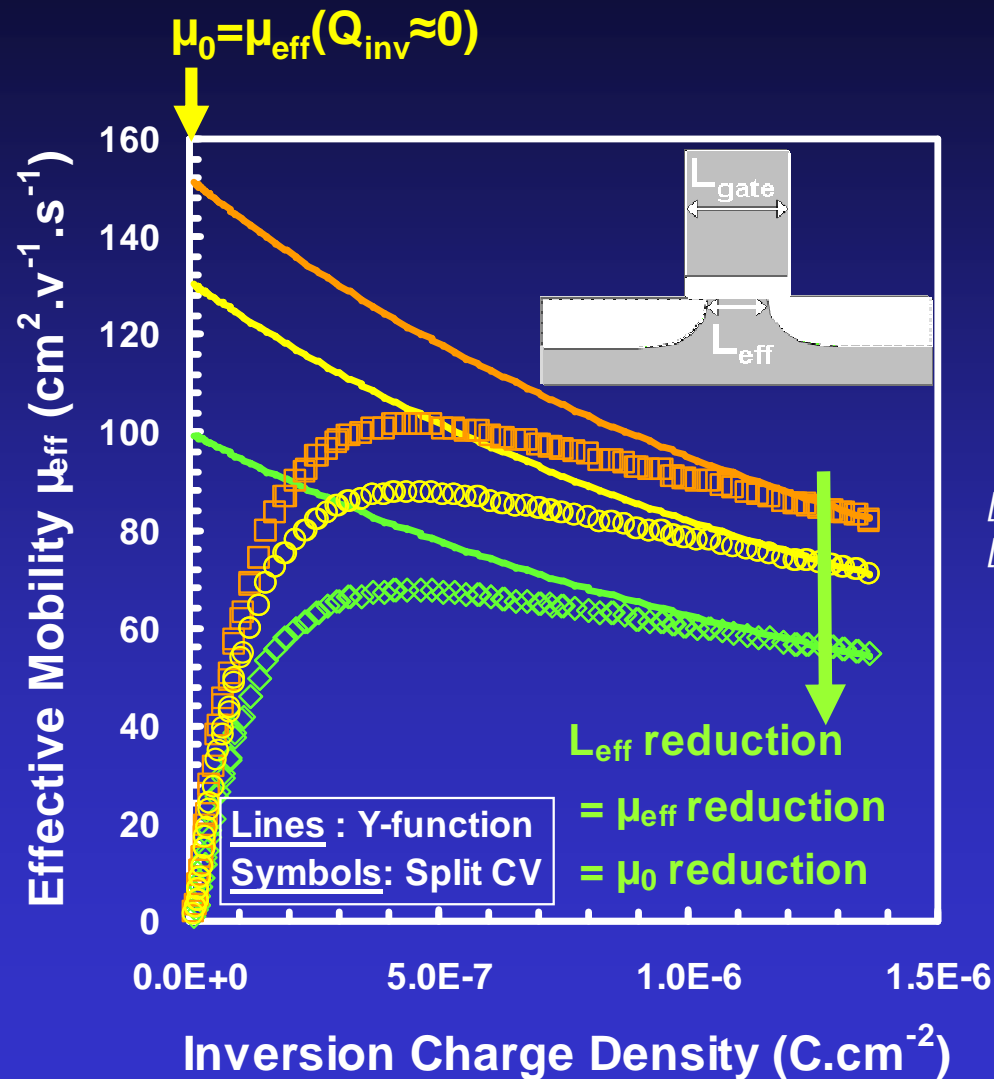
- By fitting experimental results by an empirical model in order to provide a simple benchmarking tool between the different technologies

[2]: F.Andrieu et al., VLSI 05 [2]: A.Cros et al., IEDM 06

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Low field mobility

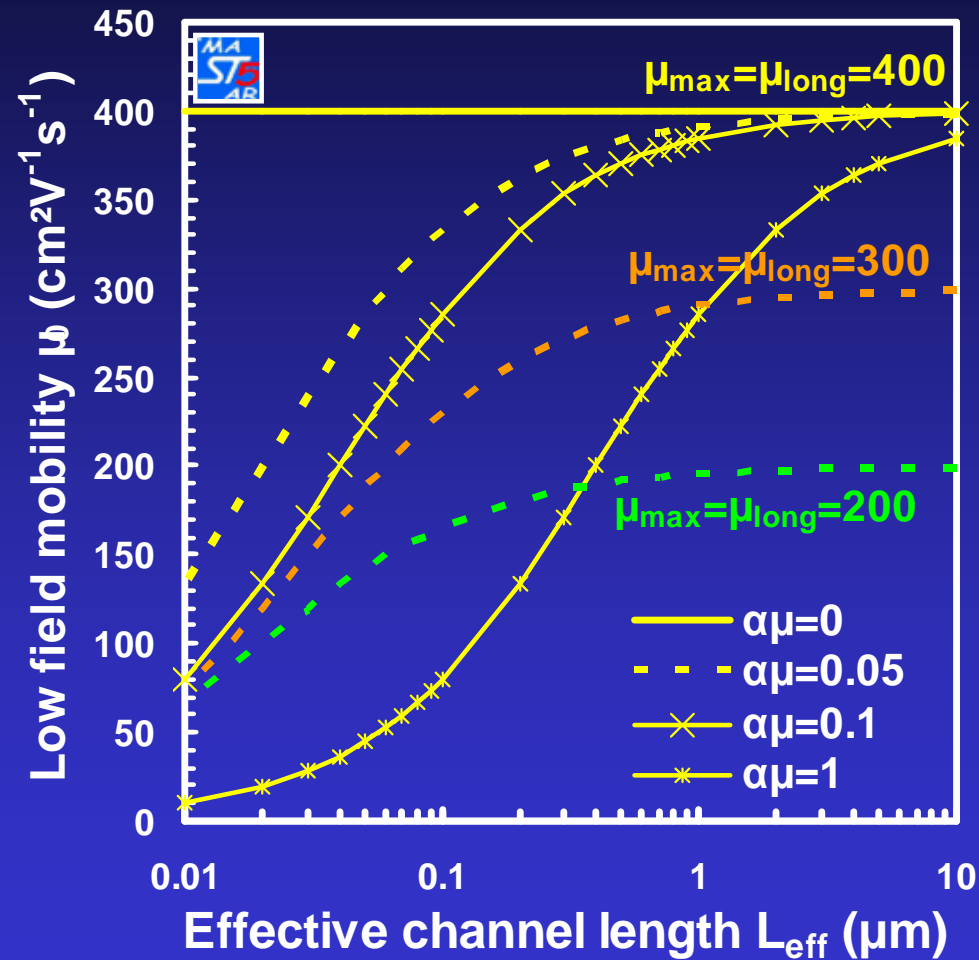


Y-function: $\mu_{\text{eff}} = \frac{\mu_0}{1 + \theta_1 \cdot V_{gt} + \theta_2 \cdot V_{gt}^2}$
 [G. Ghibaudo et al.,
 Electronics Letter, 1988]

Split C(V): $\mu_{\text{eff}} = \frac{I_d \cdot L_{\text{eff}}}{Q_{\text{inv}} \cdot V_d \cdot W_{\text{eff}}}$
 [J. Koomen et al., SSE, 1973]
 [K. Romanjek et al., EDL, 2004]

- Y function and split C(V) methods give similar results, except under V_{th}
- L_{eff} shrink implies μ_0 degradation and μ_{eff} degradation

Empirical Model



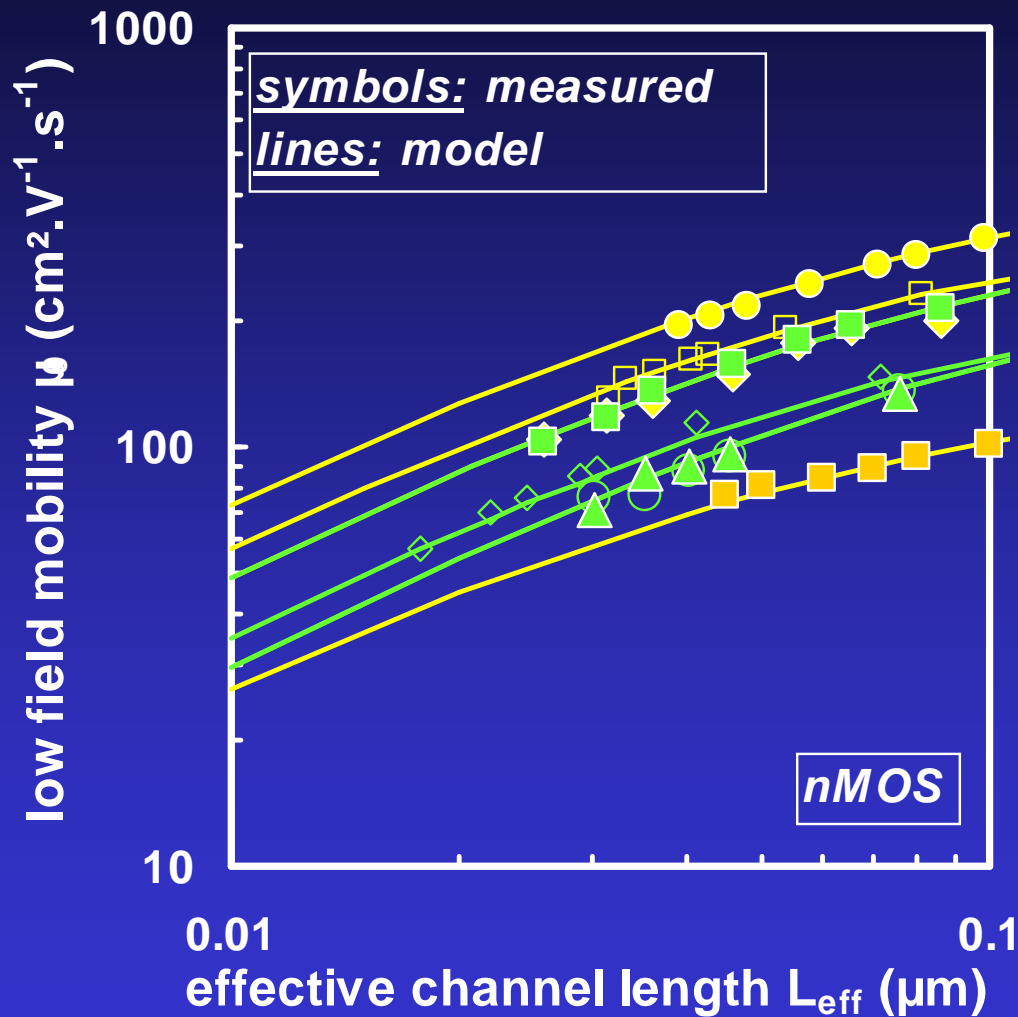
degradation factor

Model :
$$\frac{1}{\mu_0(L_{\text{eff}})} = \frac{1}{\mu_{\text{max}}} + \frac{\alpha_\mu}{L_{\text{eff}}}$$
 (with 2 fitting parameters)

\downarrow
maximum mobility
 \uparrow

- Zero degradation corresponding to $\alpha_\mu=0$ does not exist: α_μ cannot be lower than $\alpha_{\mu,\text{bal}}$ given by the apparent mobility reduction due to ballistic transport

Fitting or not fitting ?



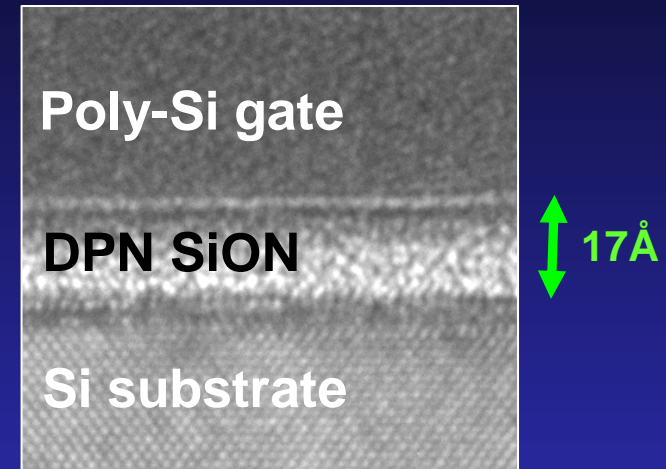
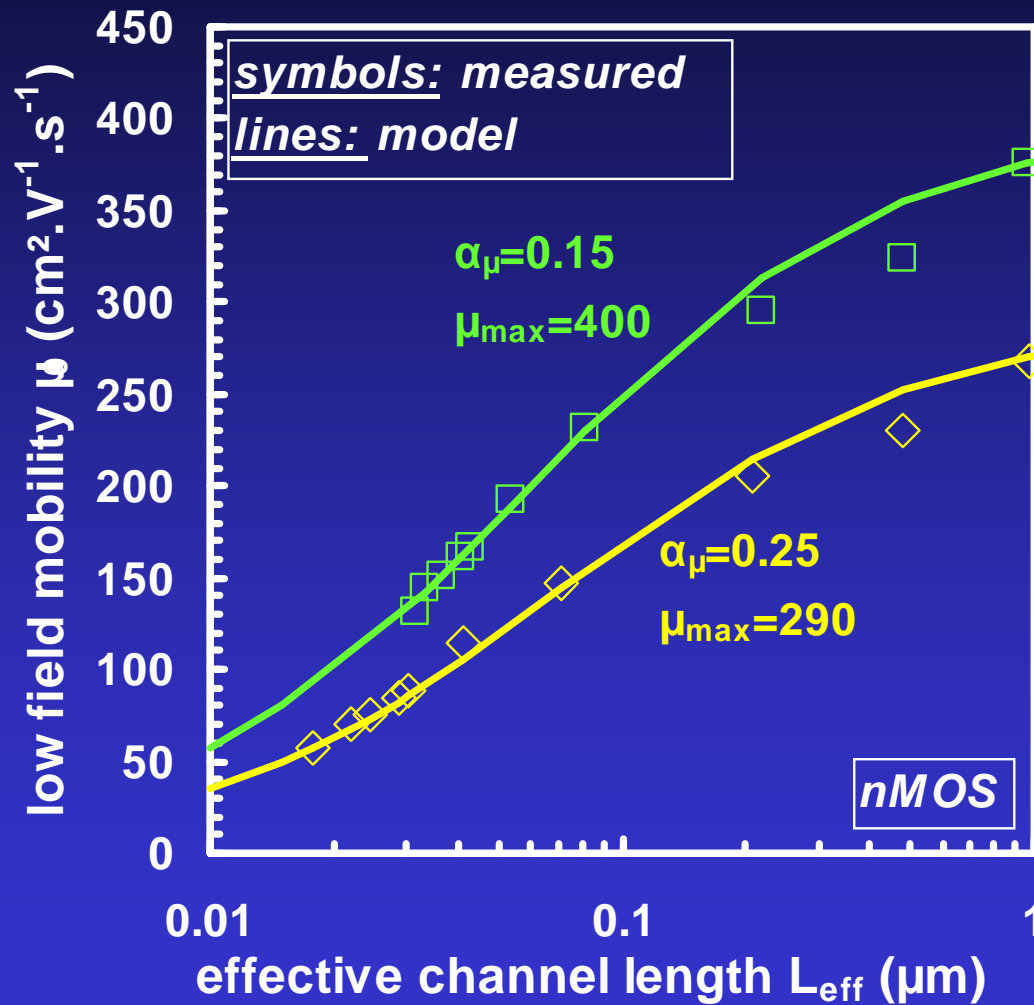
- Bulk and Ultra thin Body (UTB) results
- PolySi/SiON and Metal/High-K results

- Perfect fit is obtained on experimental data at short gate length

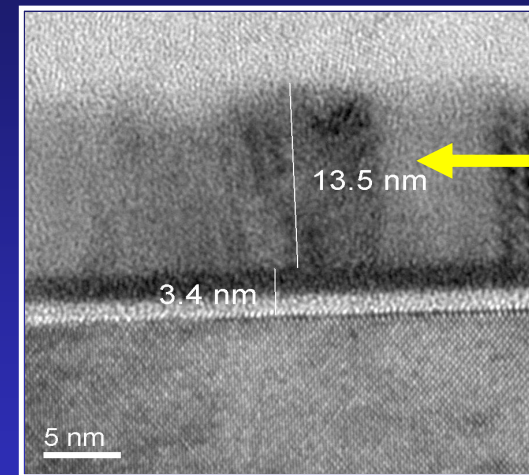
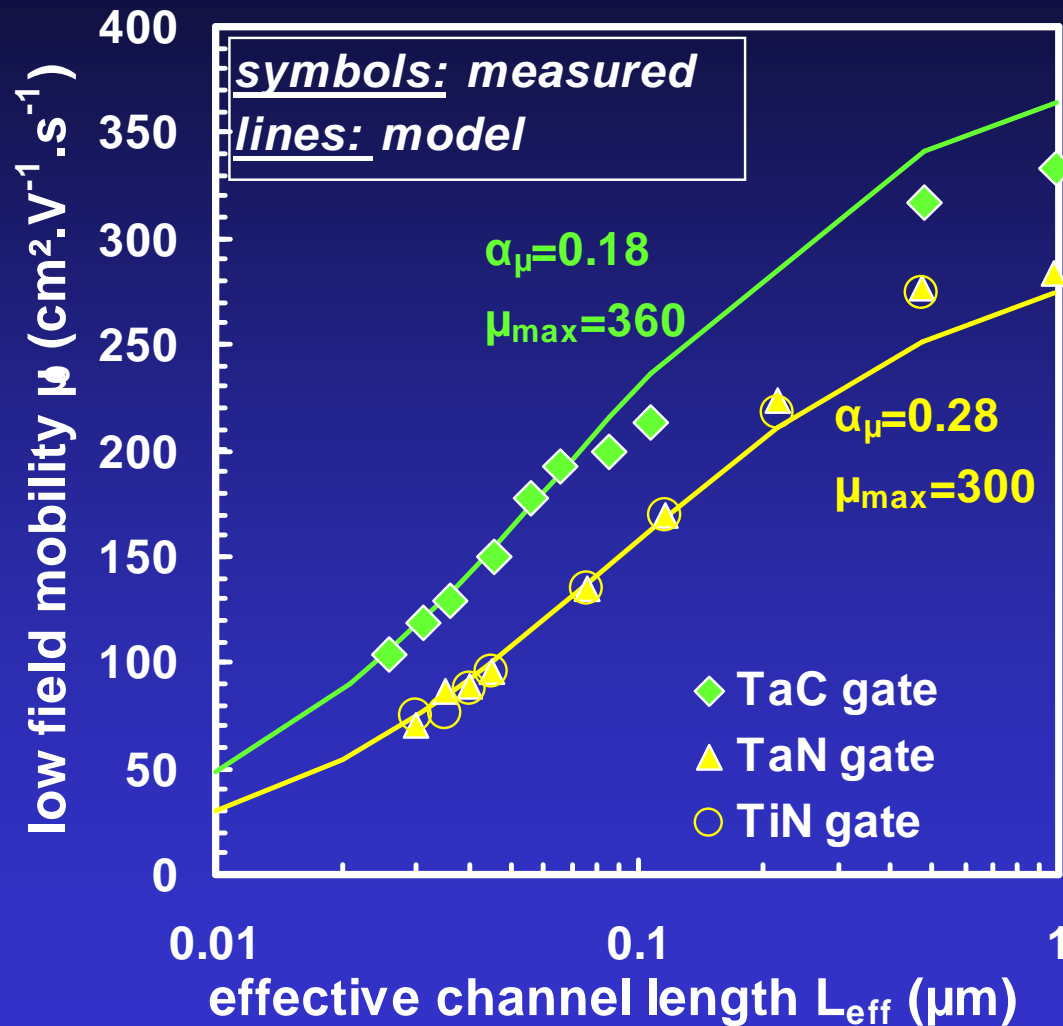
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Impact of SiON thickness



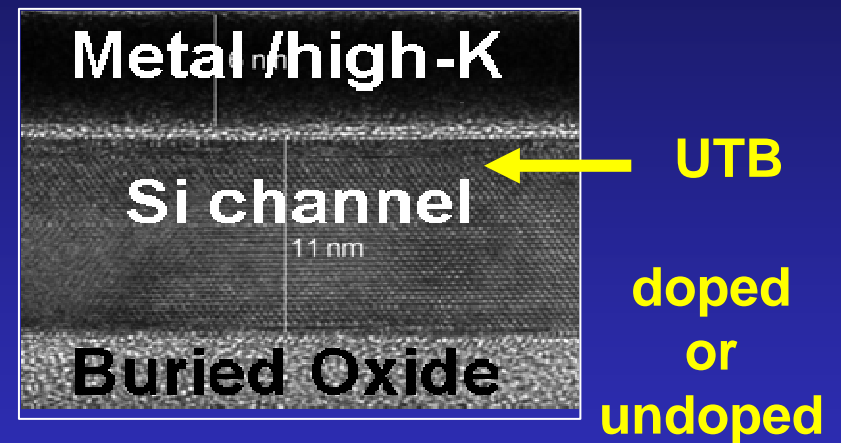
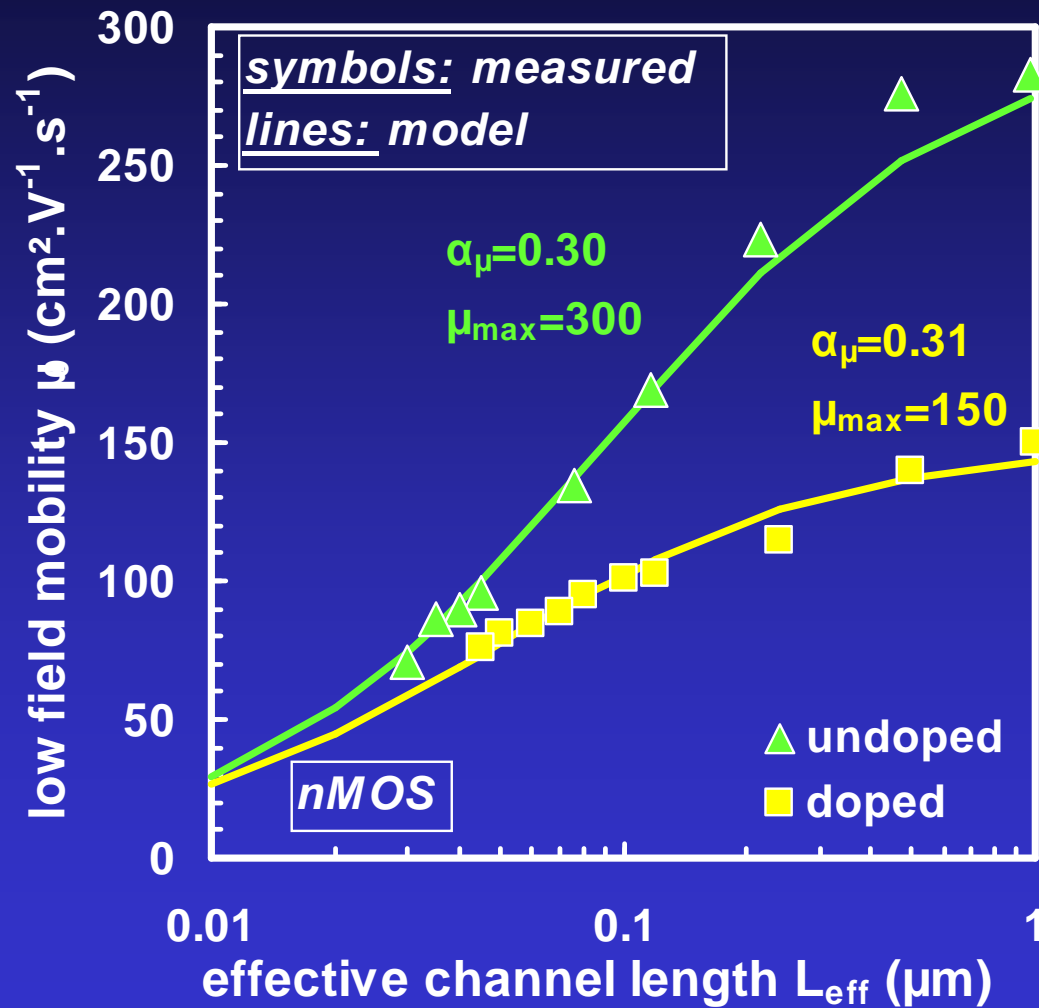
Impact of metal gate material



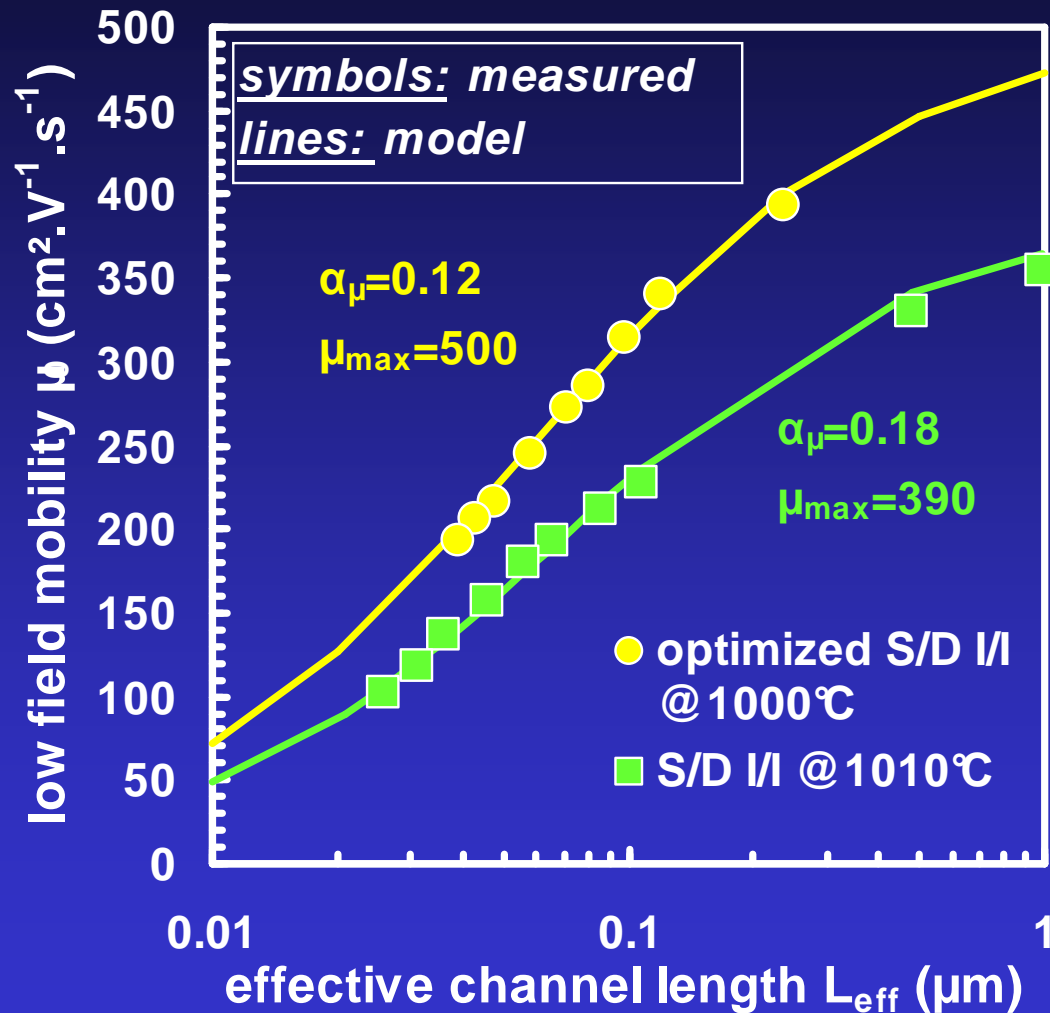
Metal gate on high-K

TaC, TaN or TiN

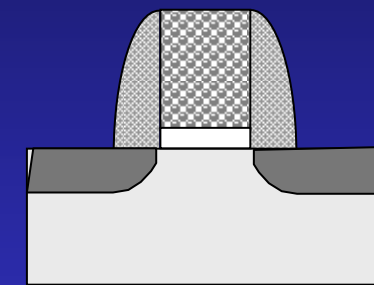
Impact of UTB doping



Impact of junction formation

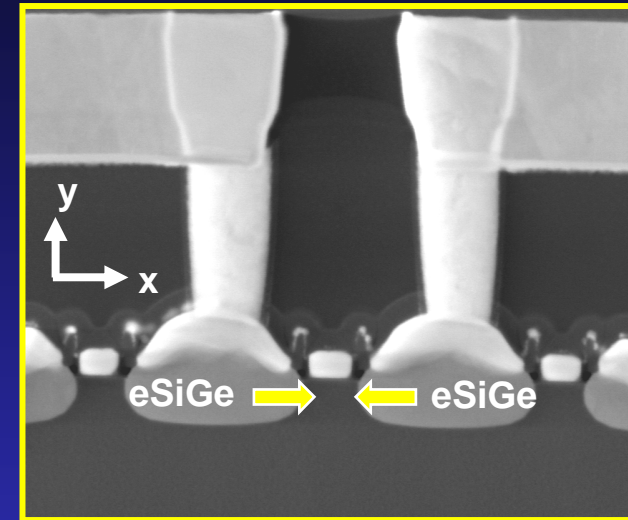
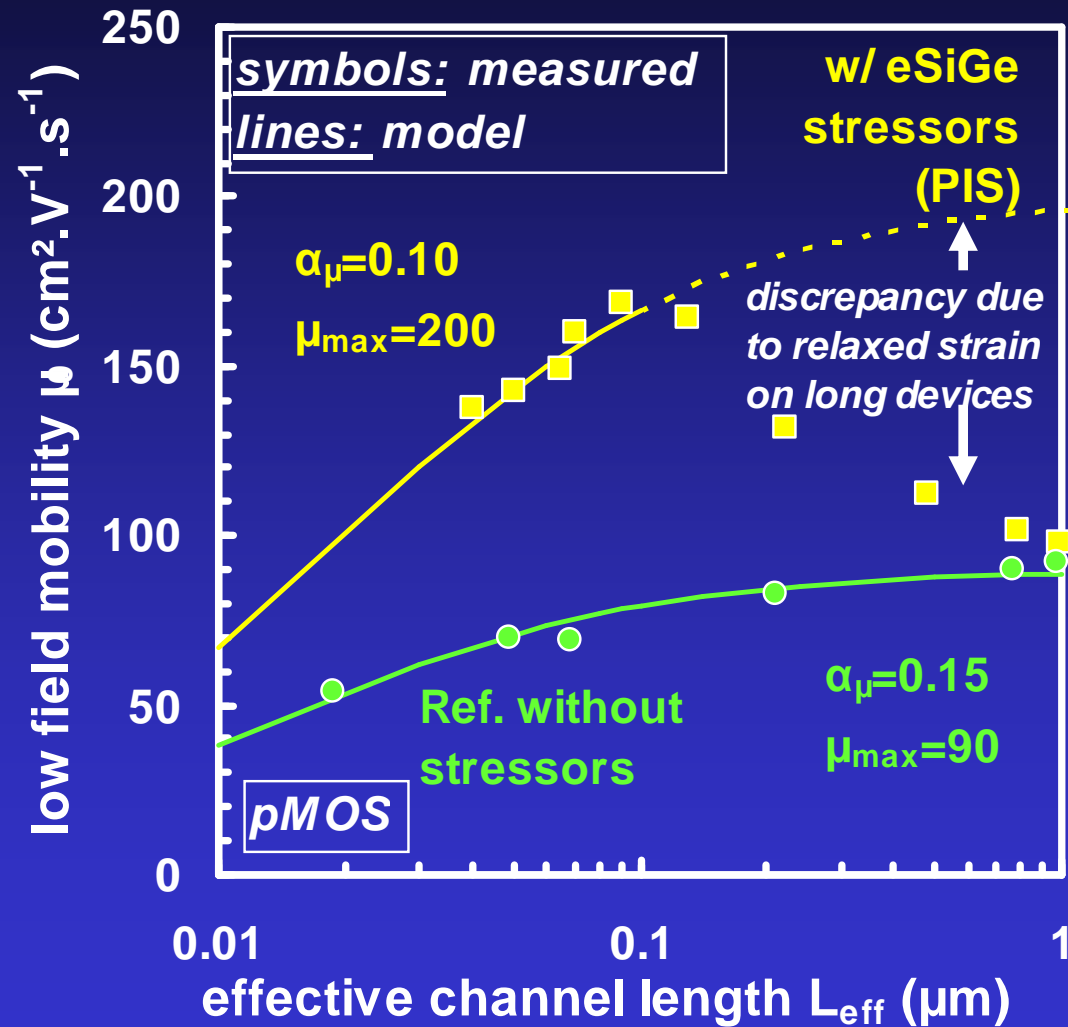


Ion Implantation

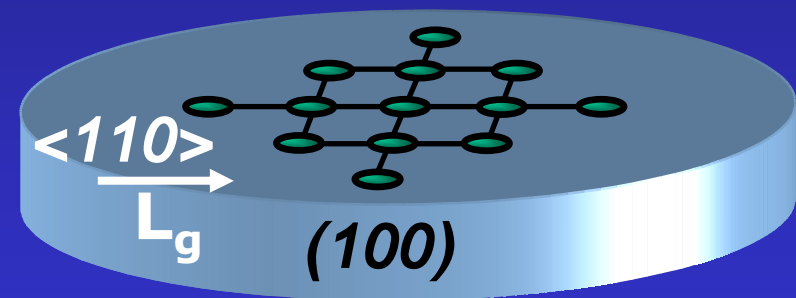
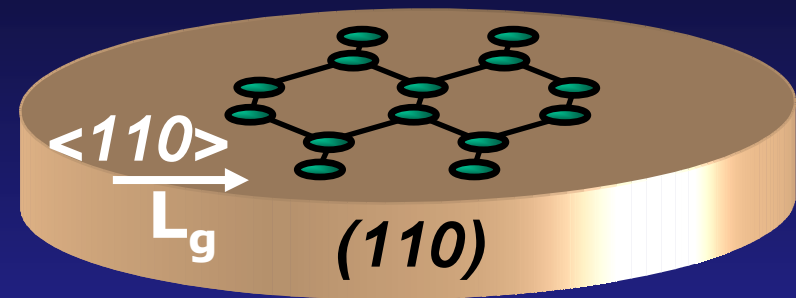
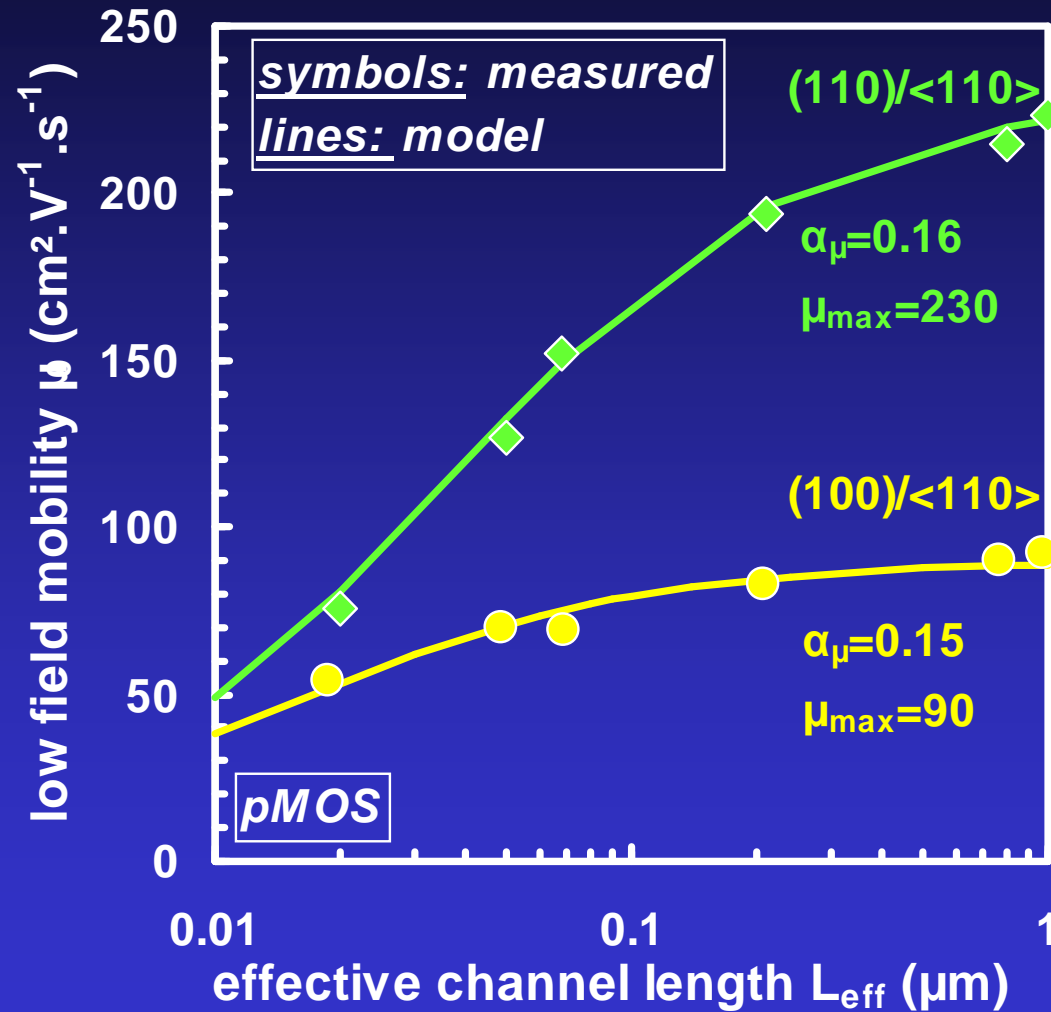


+ activation anneal

Impact of strain



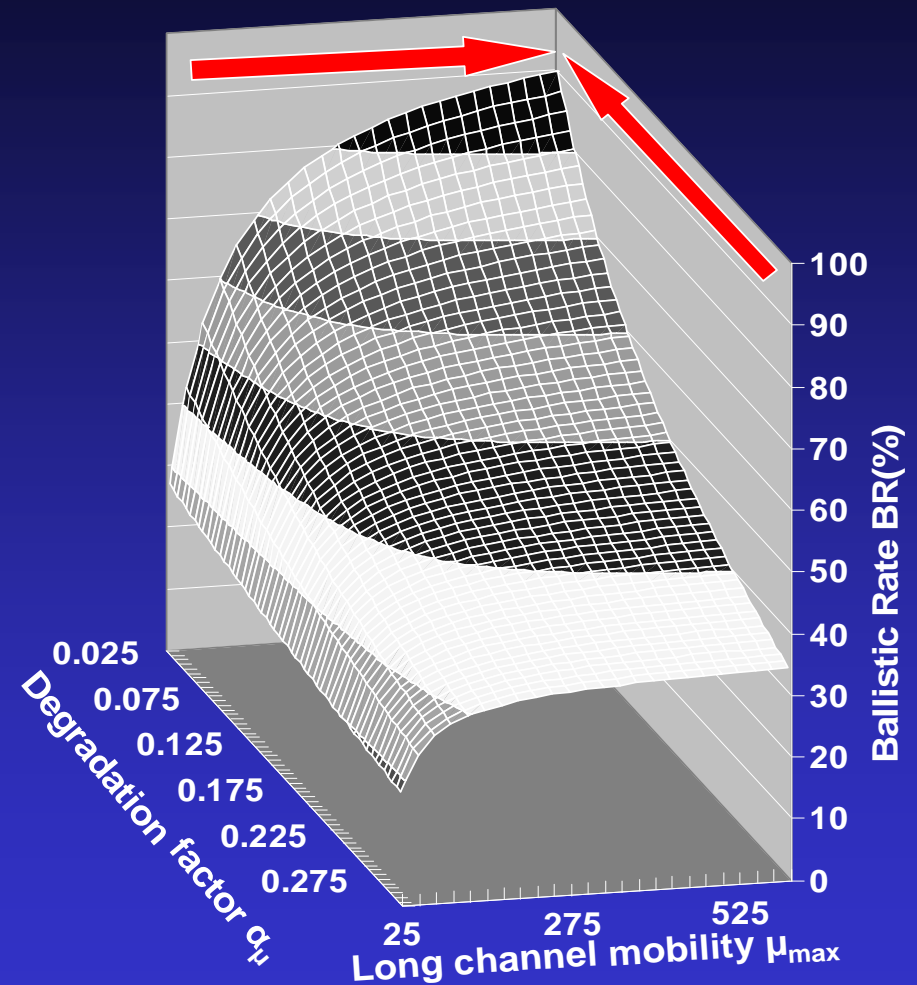
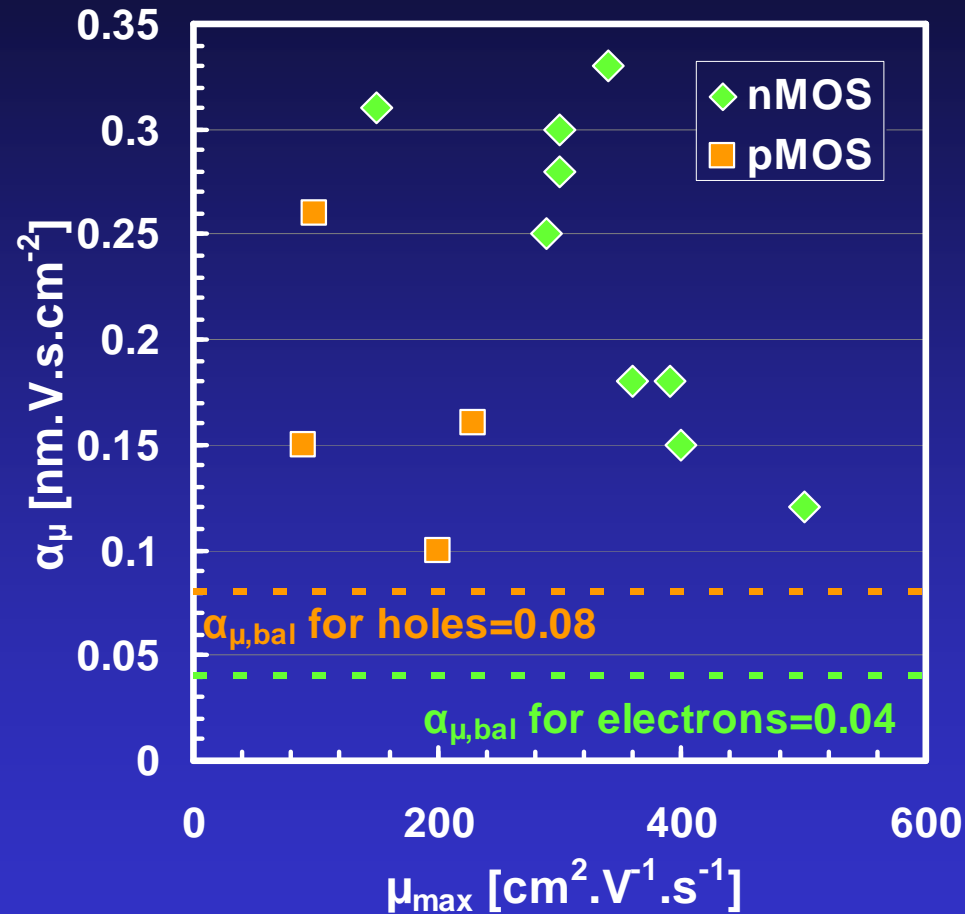
Impact of crystal orientation



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How close to the ballistic ?



- Boosting μ_{\max} and reducing α_{μ} is mandatory to reach high BR

Final benchmark & Guidelines

Techno. module	impact on μ_{\max}	impact on α_{μ}	Merit factor $\eta = \mu_{\max} / \alpha_{\mu}$
Gate stack	+	++	x2 to x4
Junctions	+	+	x2
Channel doping	++	=	x2
Process Strain	++	+	x3
Crystal orientation	++	=	X2

- Influence of each studied technological module is quantified

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Conclusion

- Easy **monitoring method** based on **simple empirical model**
- Can be used to evaluate how close to **ballistic limit** a transistor is
- Quantification of **impact** on the mobility of each **technological module**
- Final **practical guidelines** for short channel mobility improvement are given
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