InGaAs Double-Gate Fin-Sidewall MOSFET

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June 25, 2014

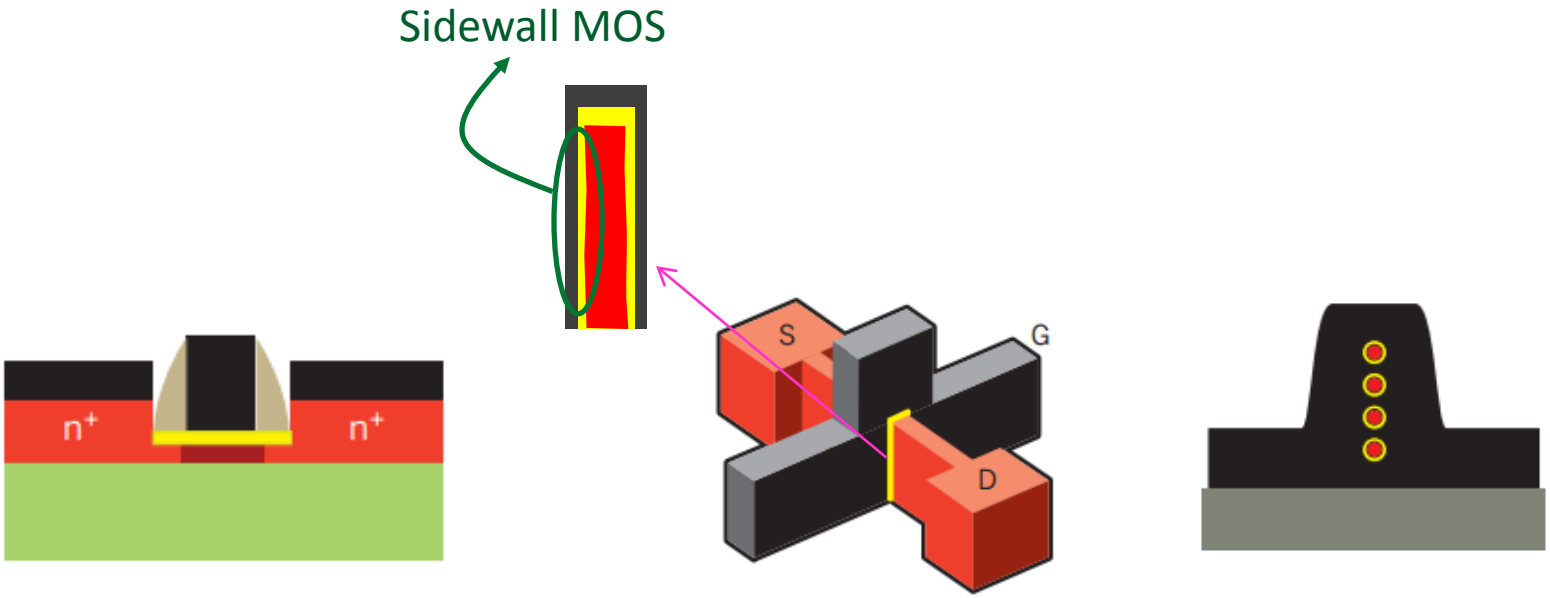
Sponsors: Sematech, Technion-MIT Fellowship,
and NSF E3S Center (#0939514)

Outline

- Motivation
- Process technology
- Results and analysis
- Conclusions

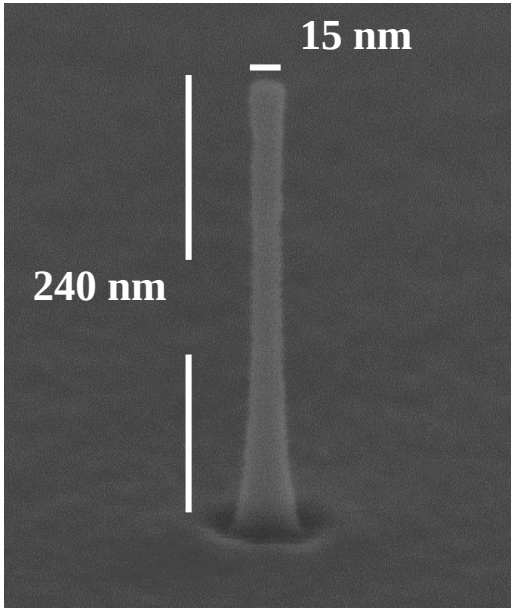
Motivation

- III-V MOSFET for sub – 10 nm CMOS
- Outstanding planar devices, but need tighter channel control through 3D designs
- Concerns about nano-structure sidewall fabricated by RIE
- Curing of plasma etching damage: forming gas annealing, digital etch



Key technologies

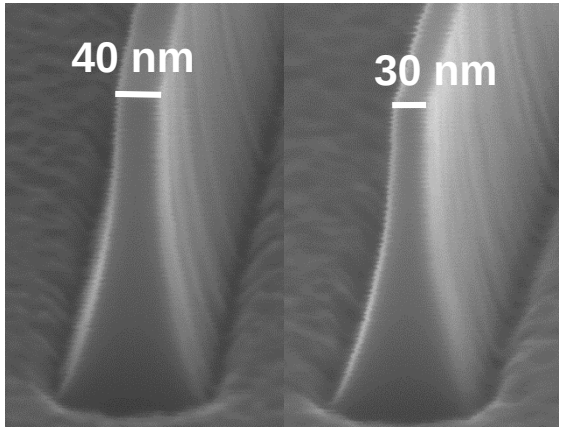
- **$BCl_3/SiCl_4/Ar$ RIE** of InGaAs nanostructures with smooth, vertical sidewall and high aspect ratio (>10).



Zhao, EDL 2014

- **Digital etch (DE)**: self-limiting O_2 plasma oxidation + H_2SO_4 oxide removal

Fins

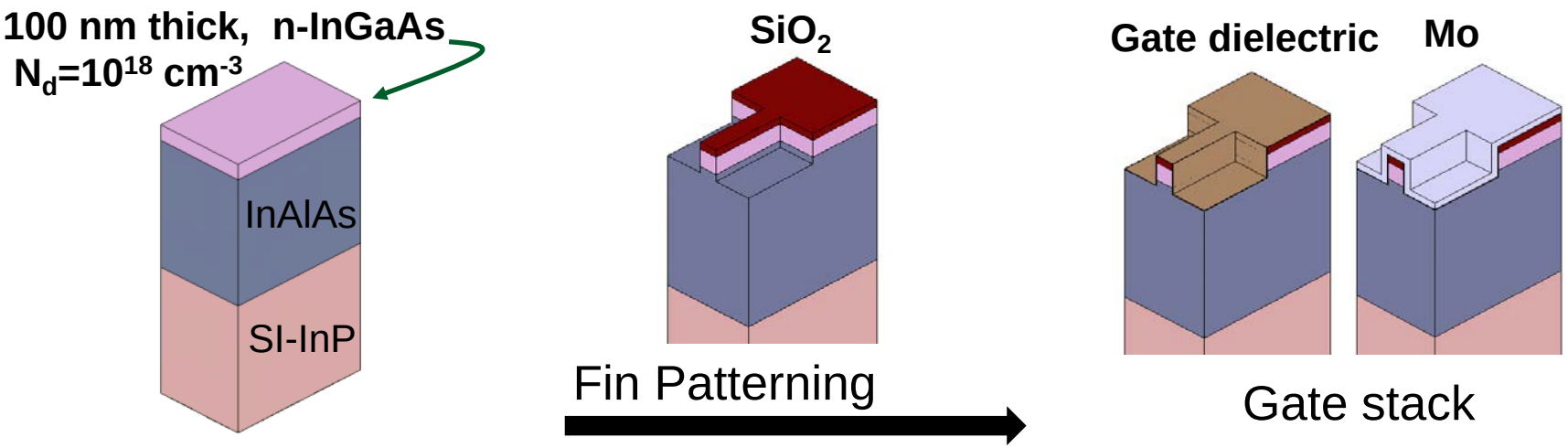


As etched ⟶ 5 cycles DE

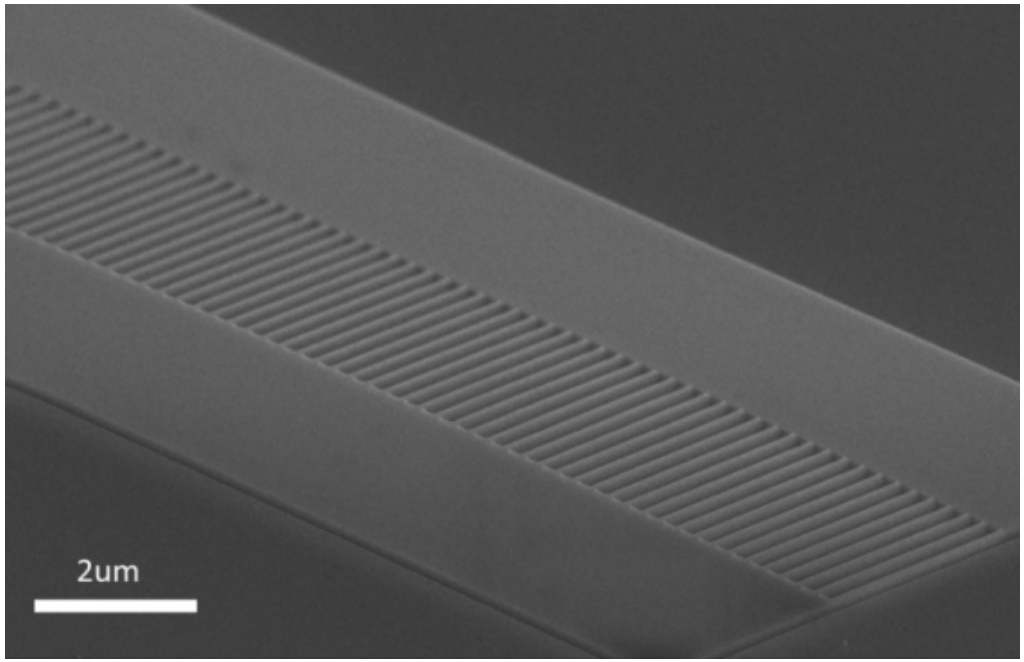
- Shrinks fin width by 2 nm per cycle
- Unchanged shape
- Reduced roughness

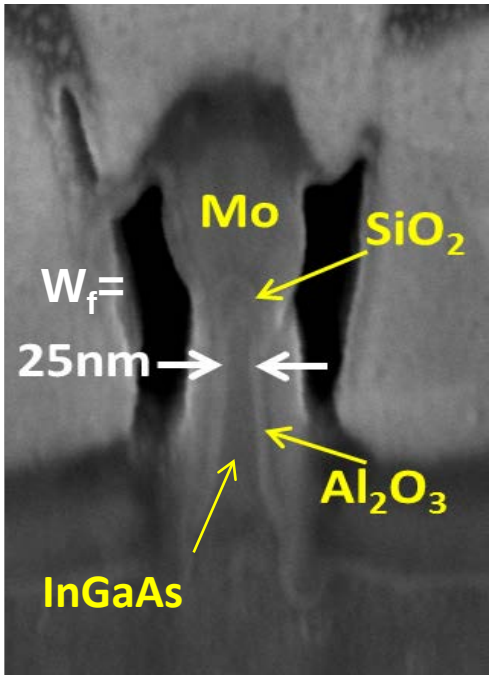
Lin, EDL 2014

InGaAs finFET process flow



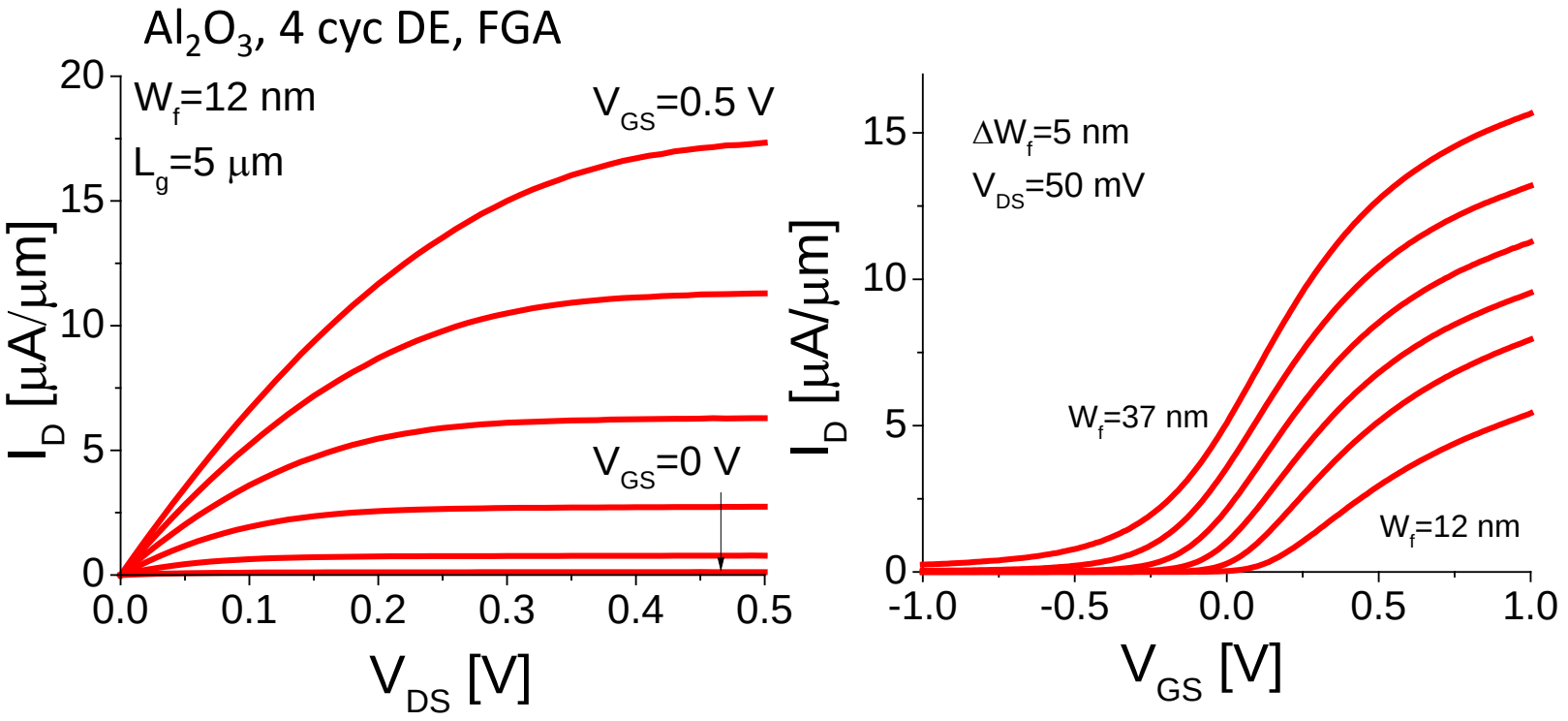
InGaAs finFETs





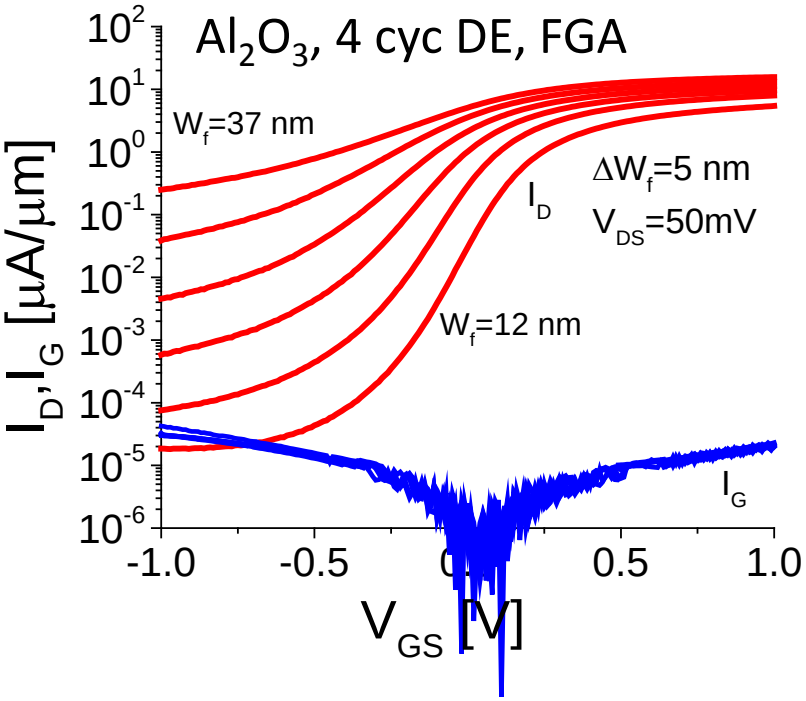
- Typical device consists of 100 fins, L_g=5 μm
- Process splits:
  - Number of digital etch cycles: 1, 2 and 4
  - HfO_2 vs. Al_2O_3 (same EOT of 4 nm)
  - w/ and w/o forming gas anneal (FGA): 30 min, 400°C

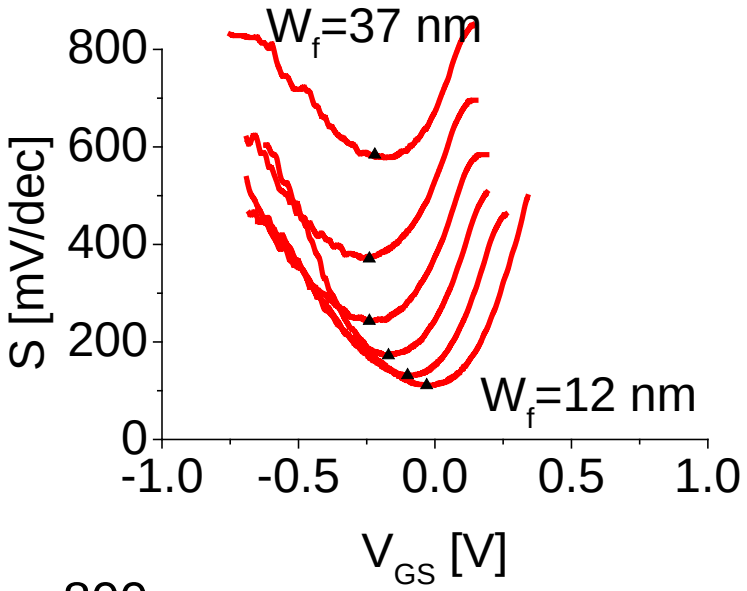
Electrical Characteristics

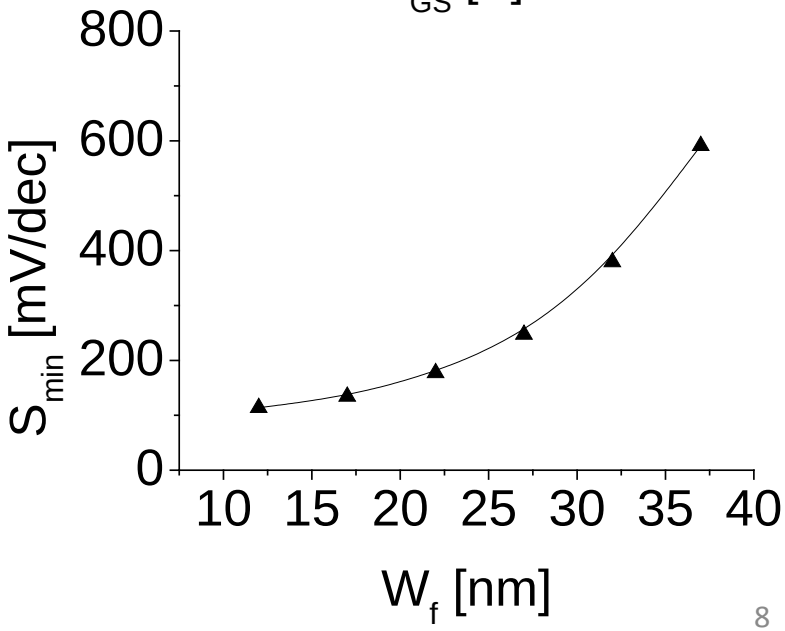


- Current normalized to active layer thickness (100 nm) and number of fins
- Good electrostatic control over fin sidewalls
- $W_f \uparrow \rightarrow V_t \downarrow$

Subthreshold characteristics

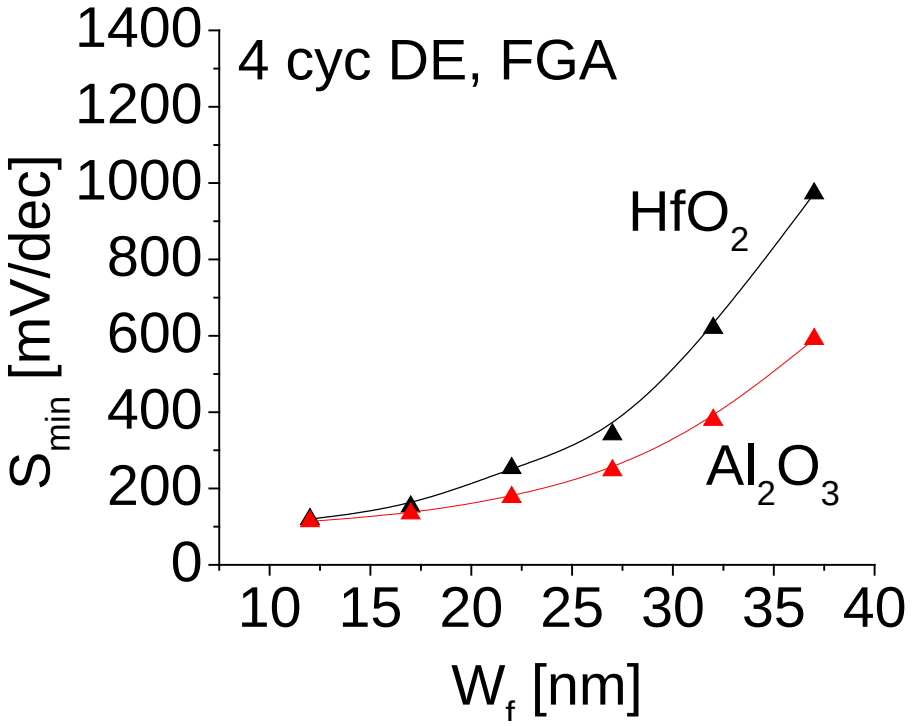






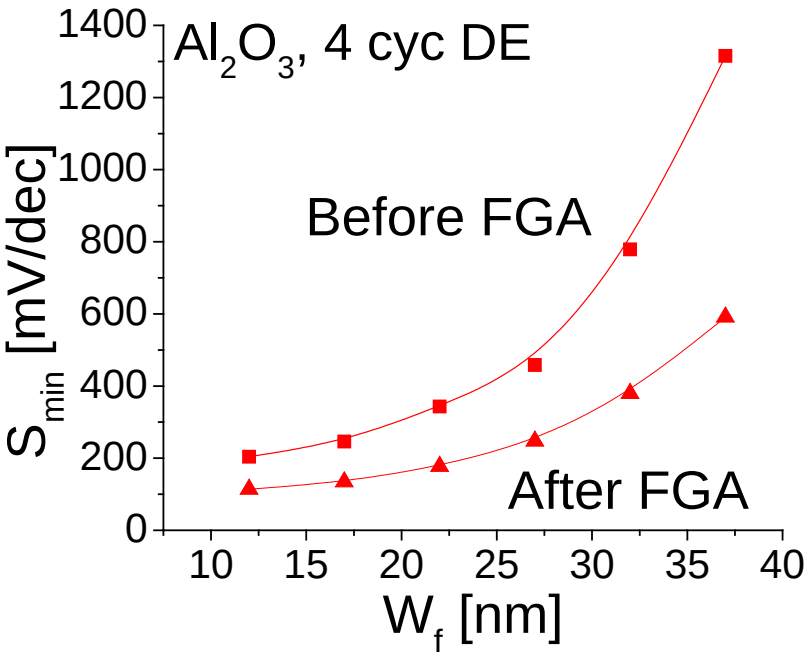
- Subthreshold characteristics unrelated to I_G and governed by D_{it} on fin sidewalls

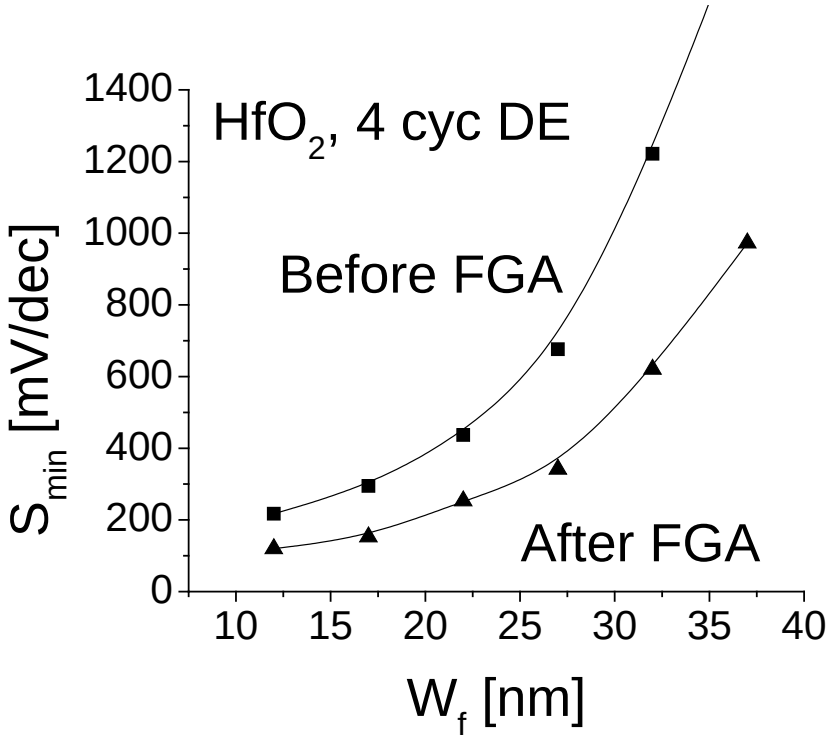
S_{min}: Al_2O_3 vs. HfO_2



- Narrow W_f : $S_{min}(HfO_2) \cong S_{min}(Al_2O_3)$
- Wide W_f : $S_{min}(HfO_2) > S_{min}(Al_2O_3)$

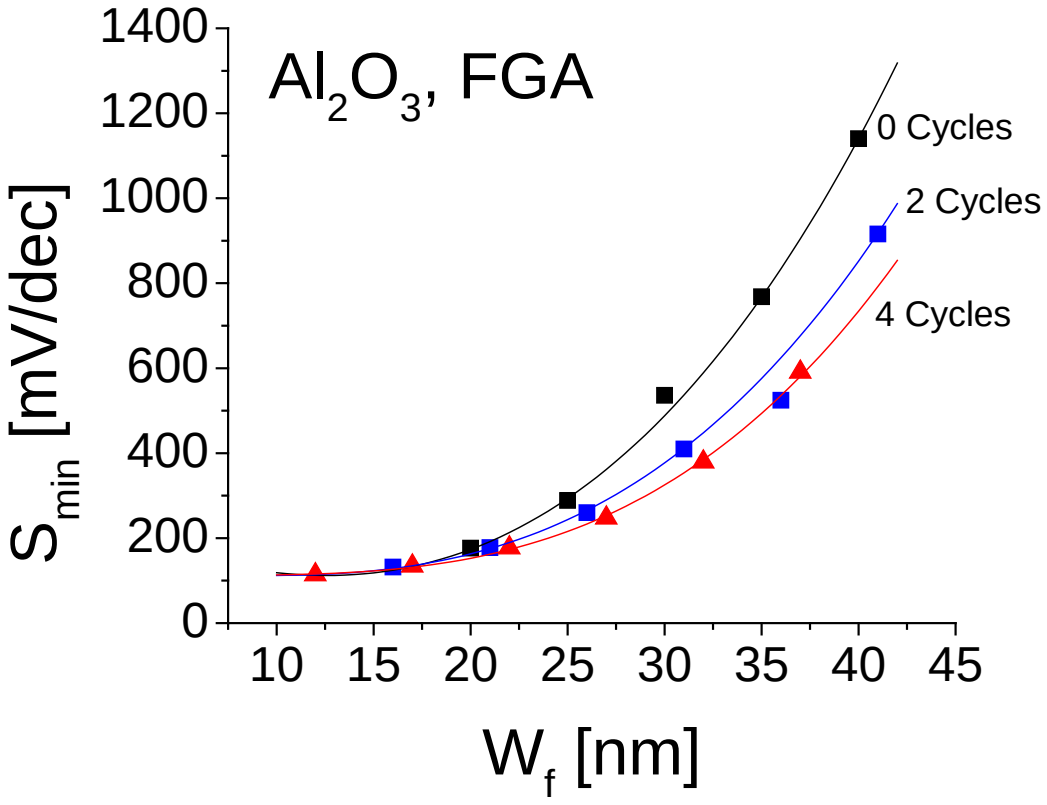
S_{min}: Effect of forming gas annealing





- FGA → S↓ at all W_f on both oxides

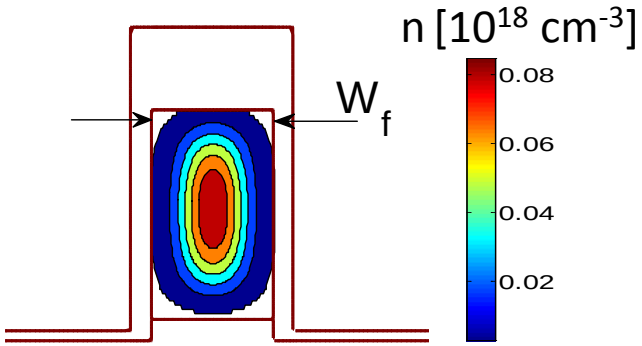
S_{min}: Effect of digital etching

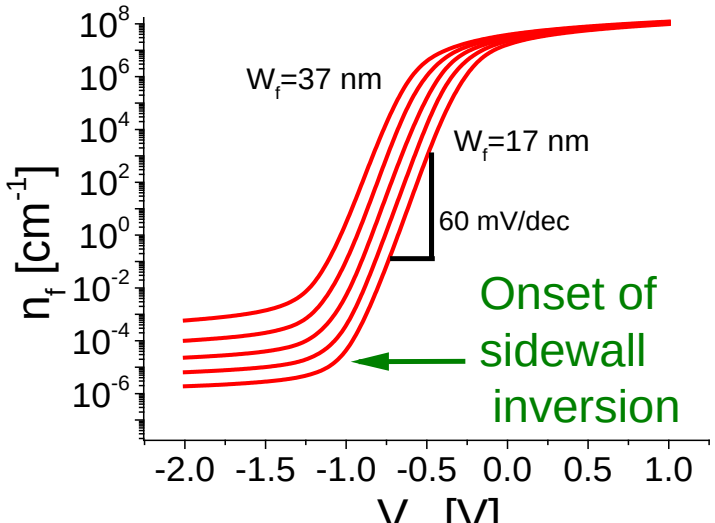


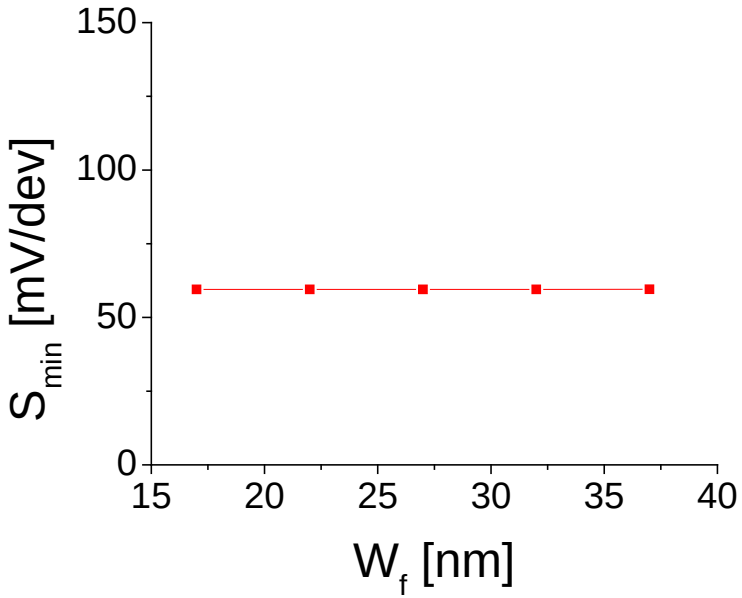
- Narrow W_f : S not affected by digital etch
- Wide W_f : #DE cycles ↑ → S_{min}↓

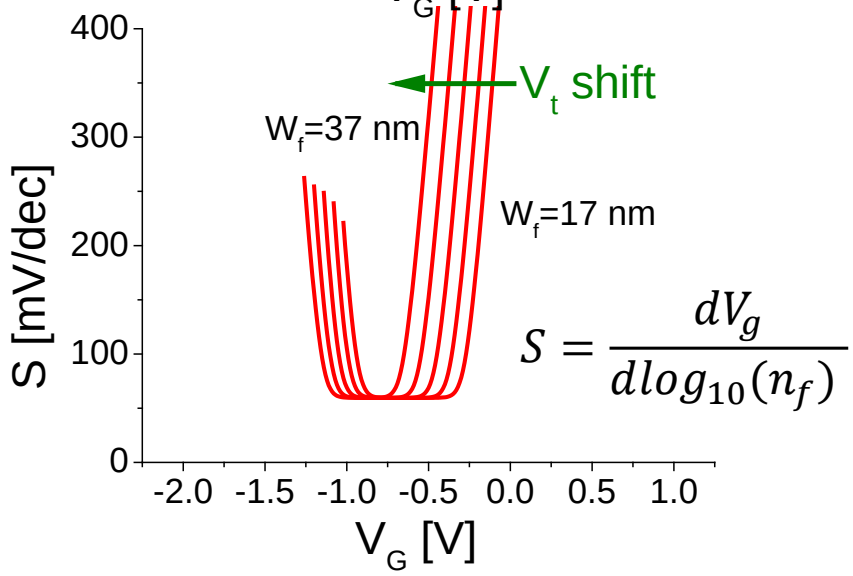
Simulations: Ideal interface

2D Poisson-Schrödinger (nextnano)



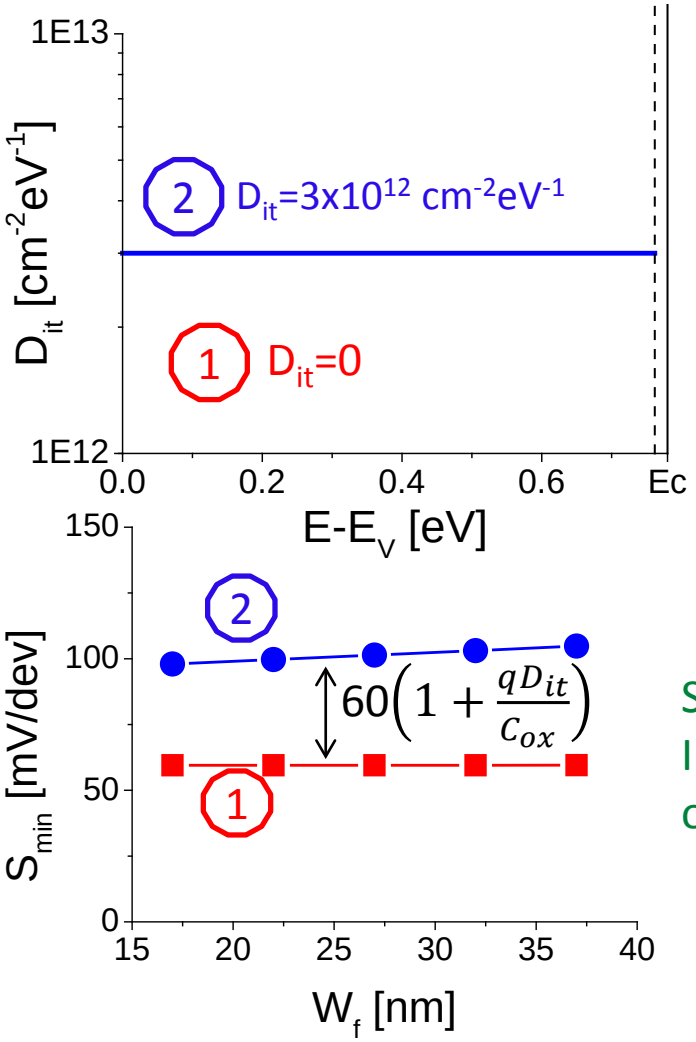


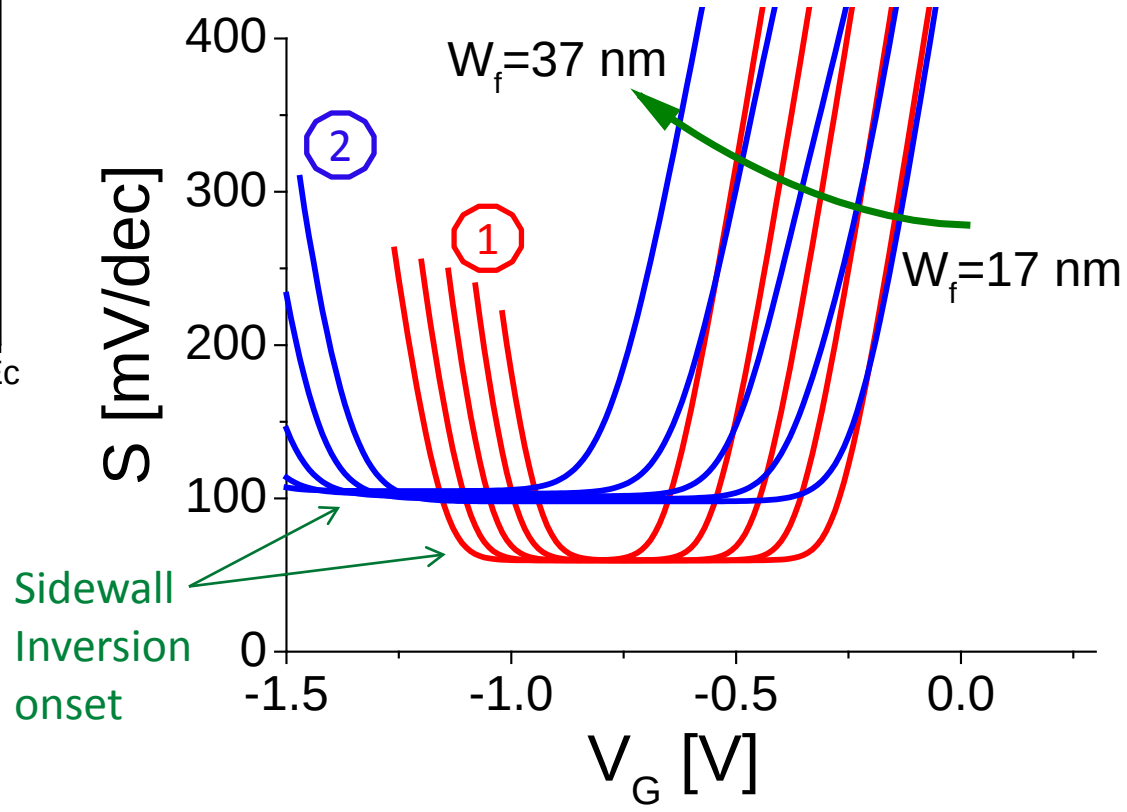




- $D_{it}=0 \rightarrow S_{min}=60$ mV/dec, independent of W_f

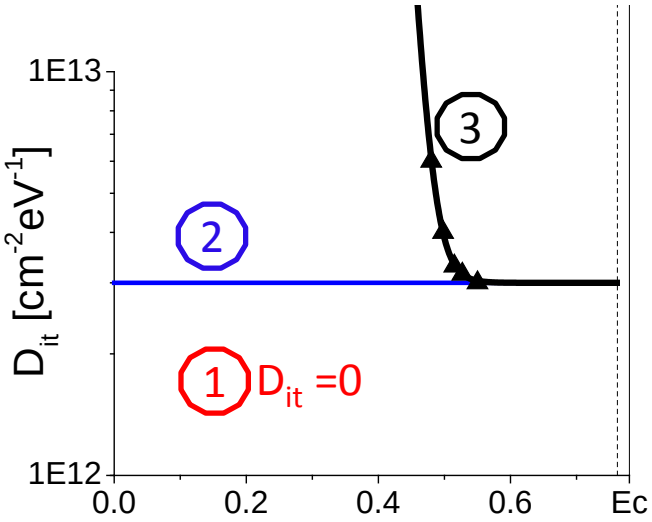
Simulations: uniform D_{it} across bandgap

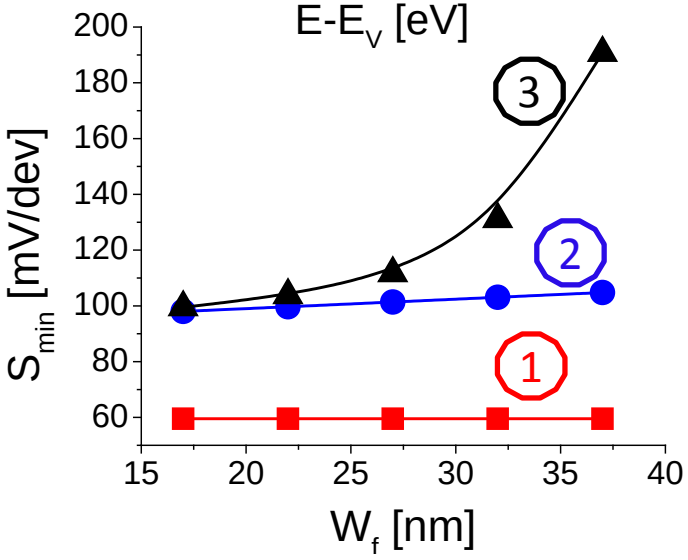


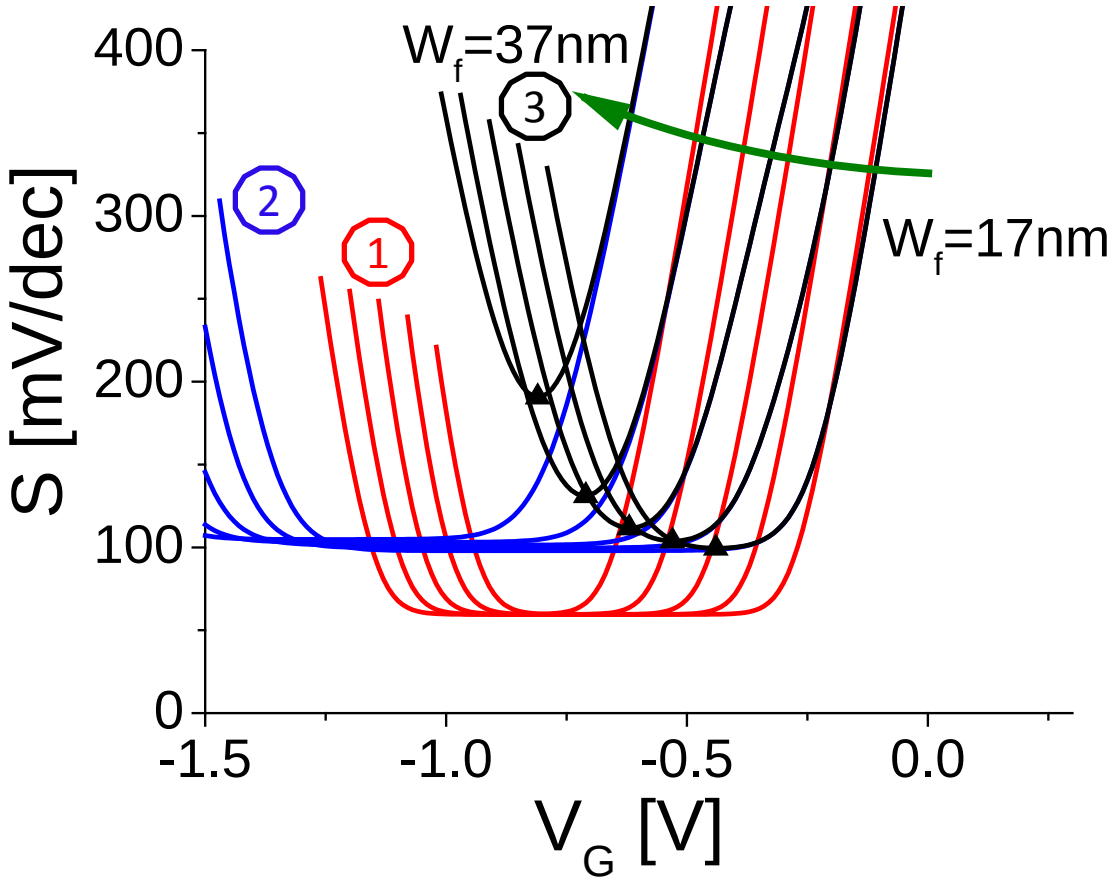


- D_{it}>0 (uniform) → $S_{min}=60\left(1+\frac{qD_{it}}{C_{ox}}\right)$, independent of W_f
- Onset of inversion shifts to negative voltage (stretch out)

Simulations: D_{it} rising toward VB



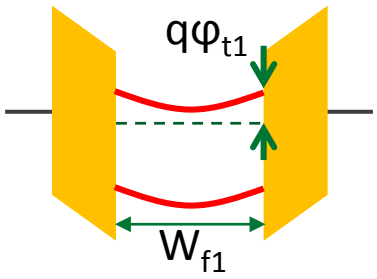




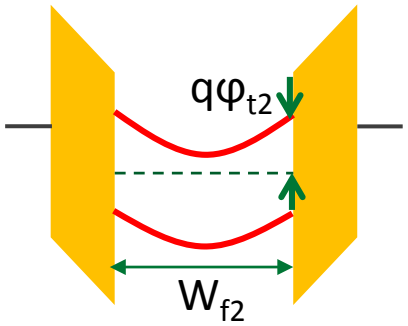
- D_{it} rising towards VB: $W_f \uparrow \rightarrow S_{min} \uparrow$
- S_{min} for different W_f probe D_{it} at different locations in the band gap

Simulations: $S_{min} \leftrightarrow \varphi_s$

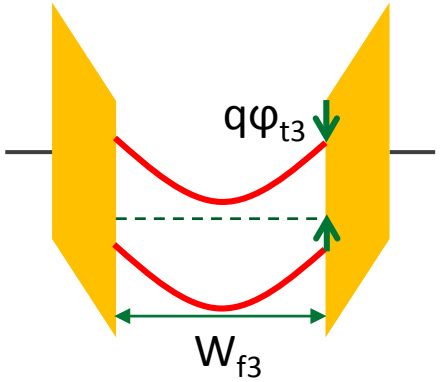
W_{f1}

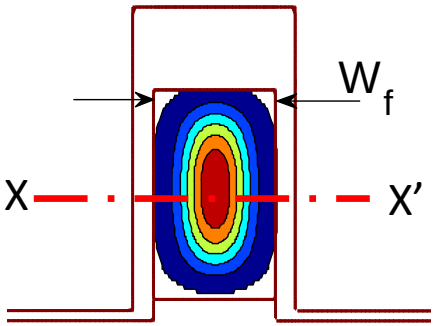


$W_{f2} > W_{f1}$



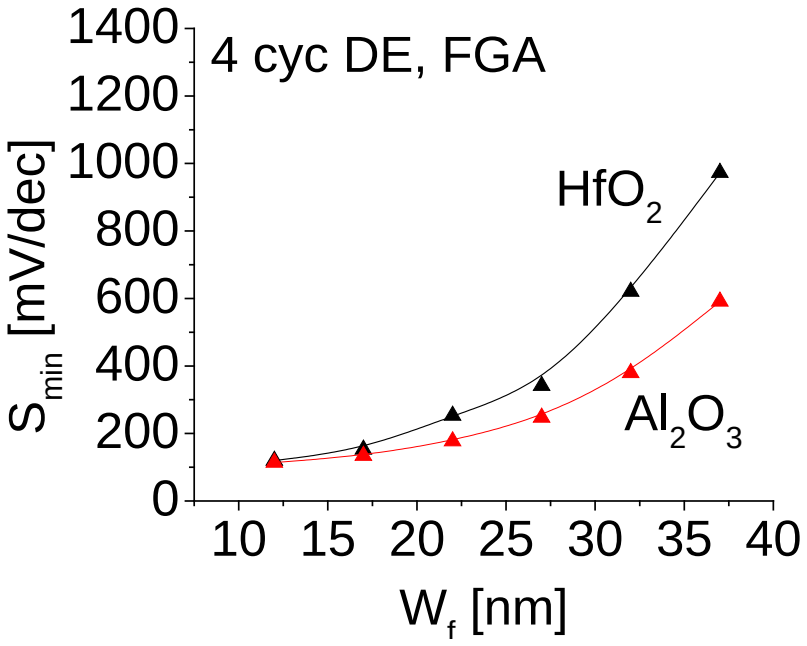
$W_{f3} > W_{f2}$

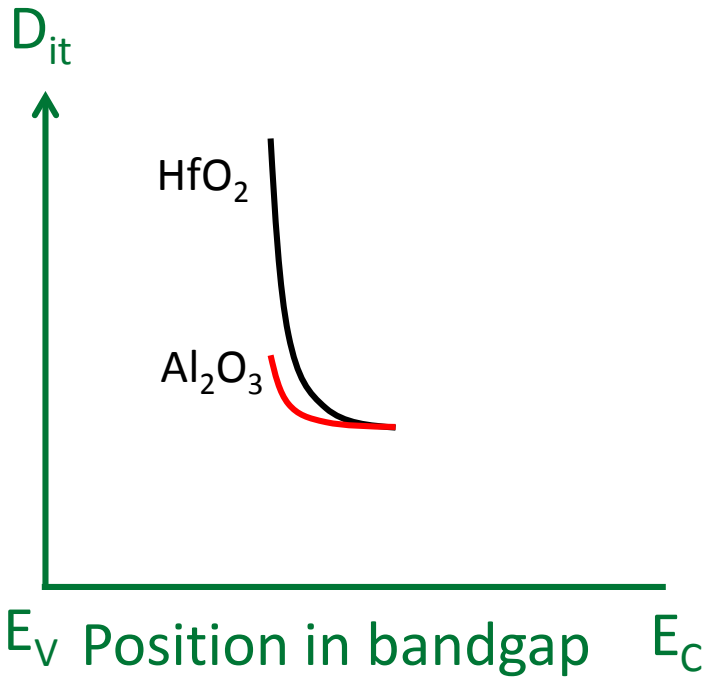




- $W_f \uparrow \rightarrow |\varphi_t| \uparrow \rightarrow |V_t| \uparrow$ (negative V_t shift)
- $W_f \uparrow \rightarrow S_{min}$ probe D_{it} closer to VB

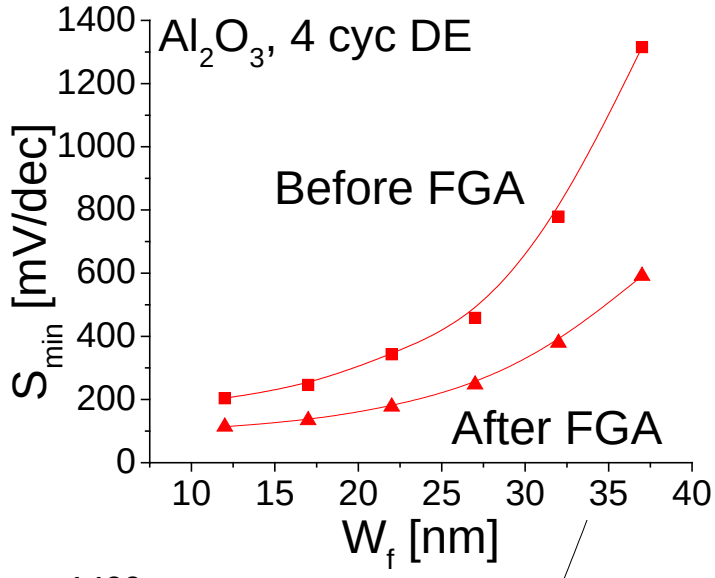
Effect of Oxide type on D_{it} profile

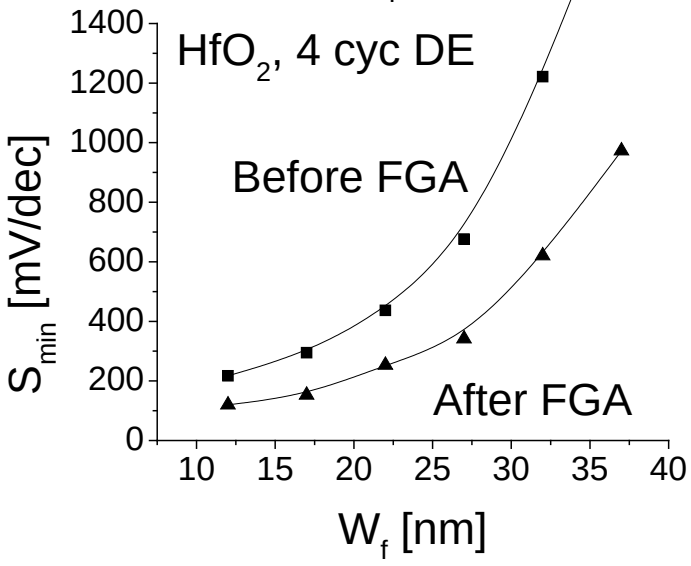


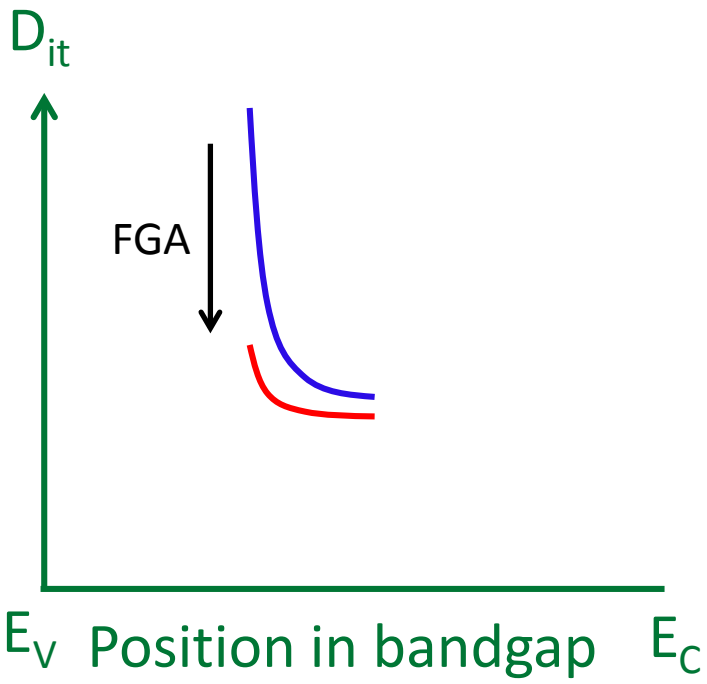


- Al_2O_3 yield better D_{it} than HfO_2in lower part of bandgap

Effect of FGA on D_{it} profile

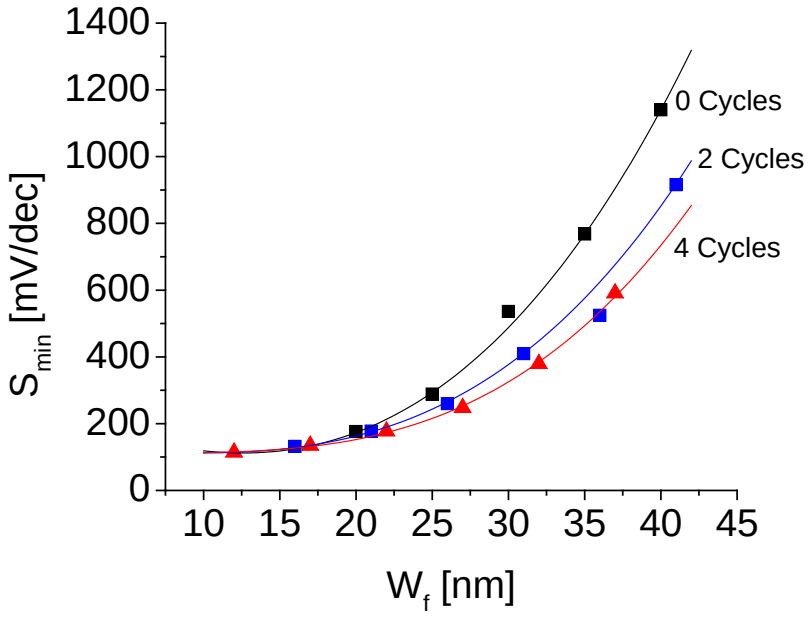


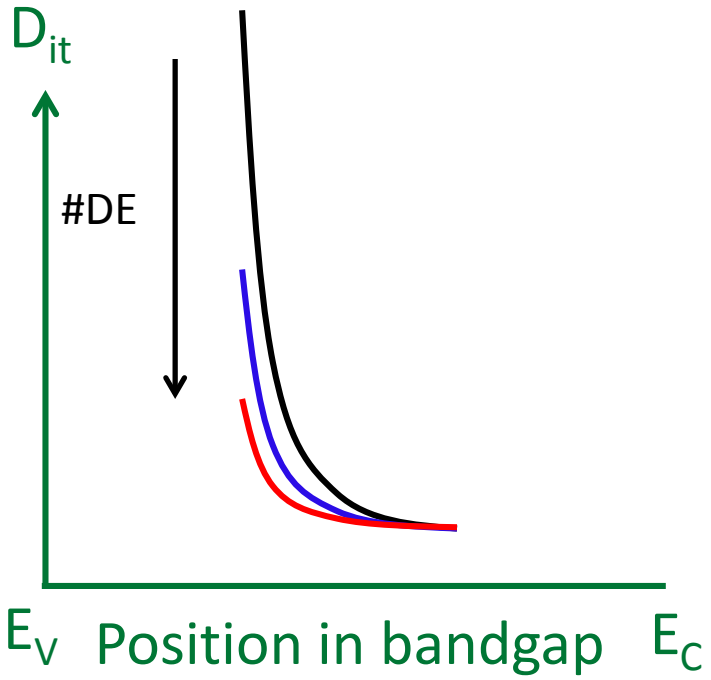




- FGA reduces D_{it} everywhere in bandgap

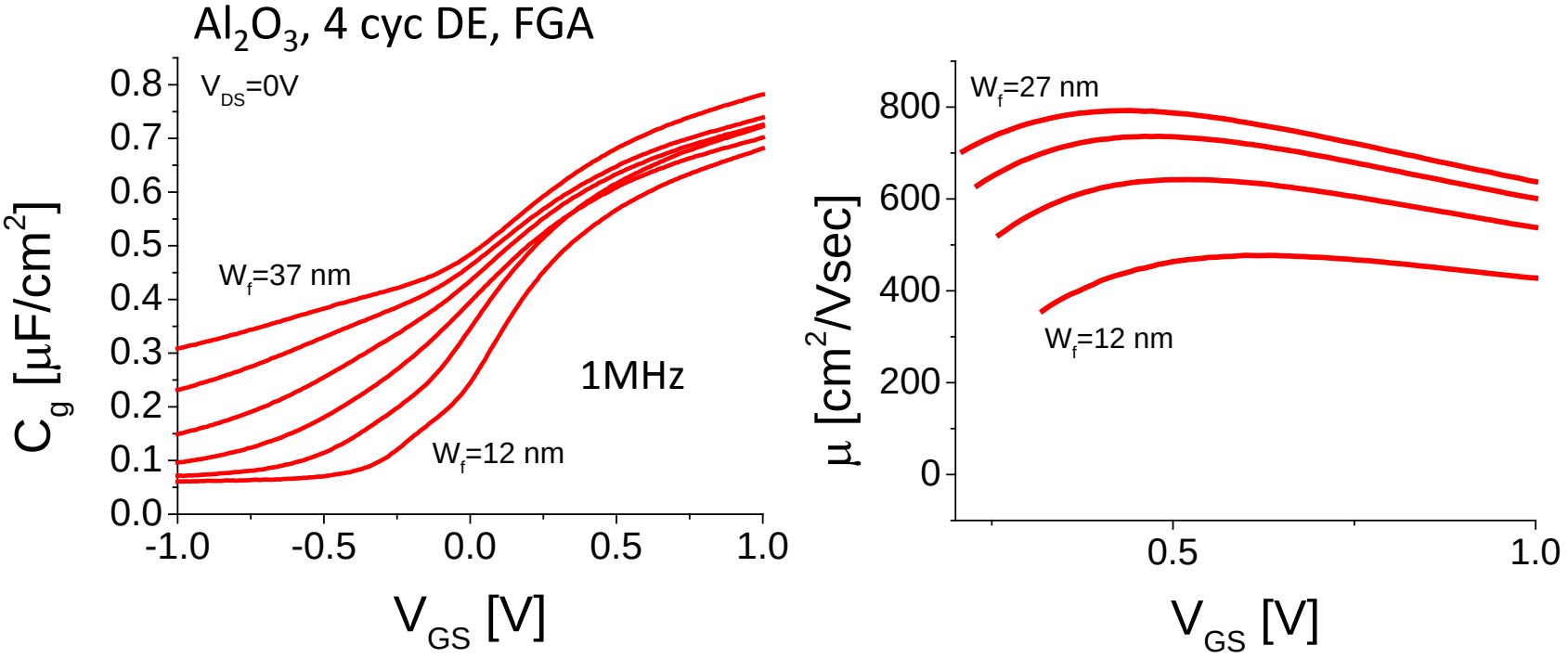
Effect of DE on D_{it} profile





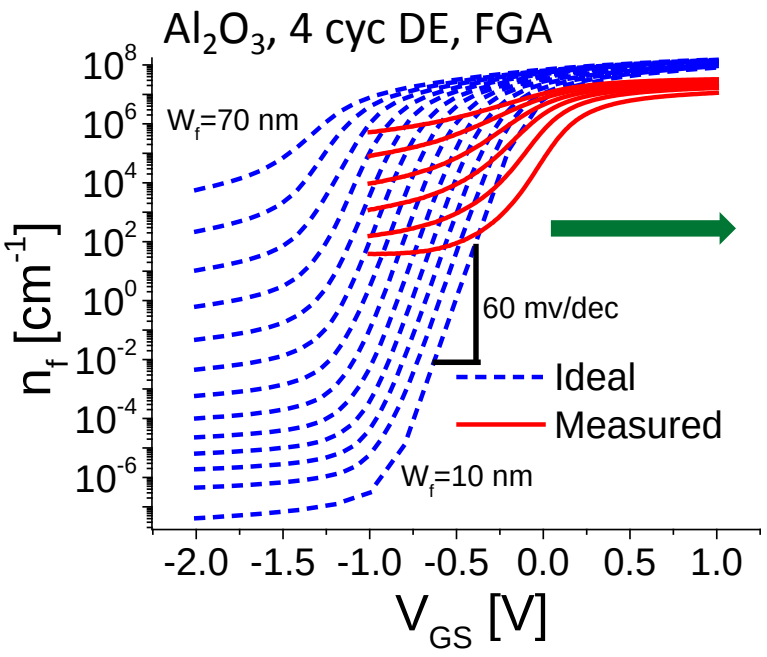
- DE reduces D_{it} in lower part of bandgap

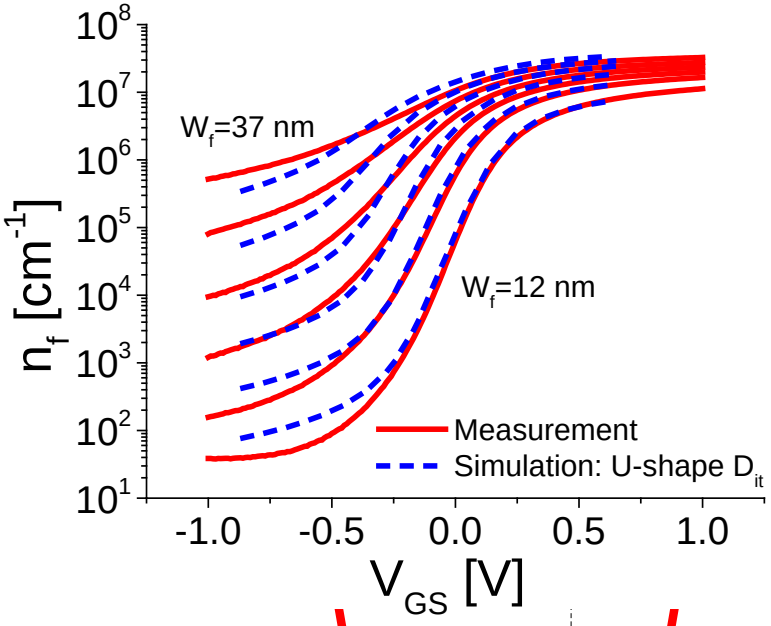
Towards a more detailed analysis: Mobility extraction



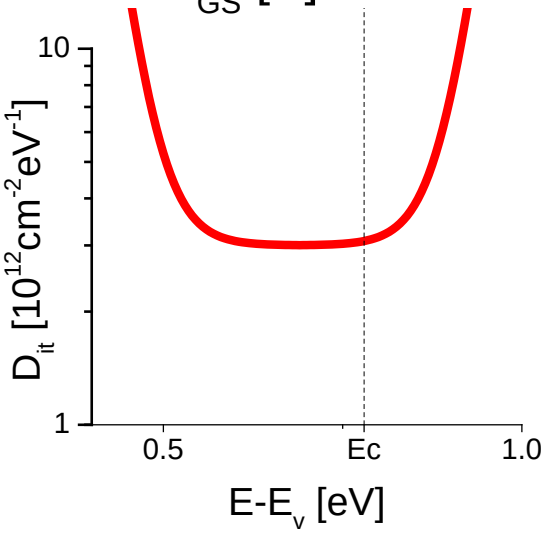
- Mobility is 5-7 times smaller than expected
- $W_f \downarrow \rightarrow \mu\downarrow \rightarrow$ sidewall scattering
- From I_D and $\mu \rightarrow$ extract n_f

Fitting of D_{it} profile

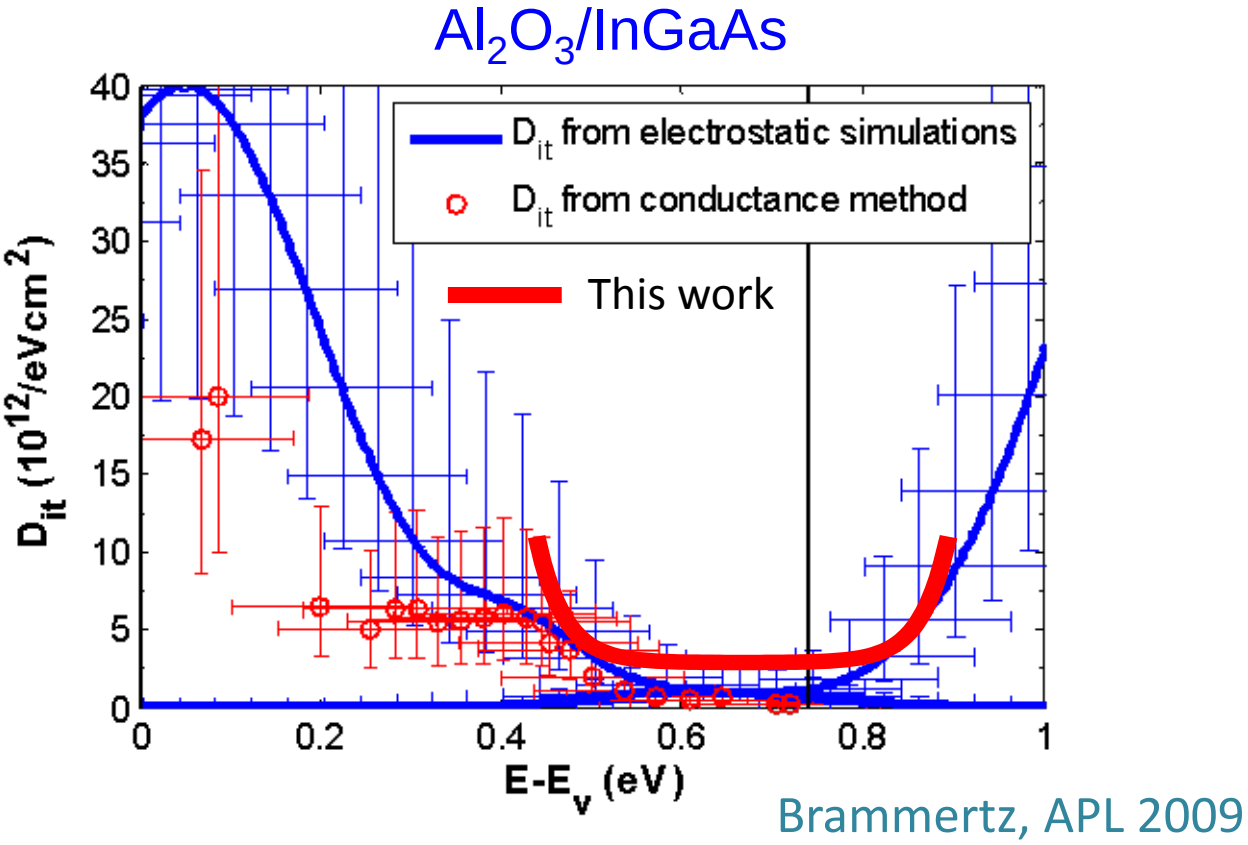




- U-shape D_{it} profile provides excellent agreement with measurements



Comparison to planar structures

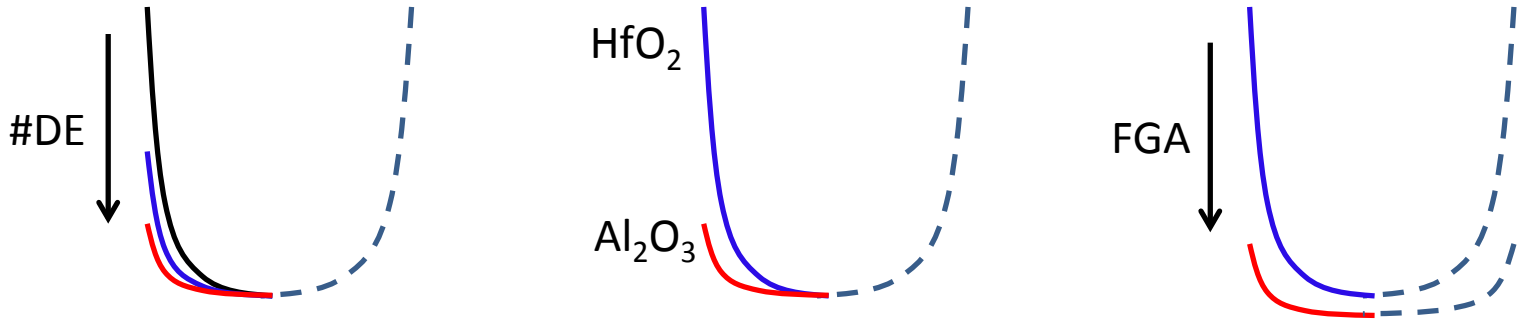


Brammertz, APL 2009

- D_{it} distribution on properly prepared dry etched sidewalls approaches that of planar structures

Conclusions

- Study of D_{it} on dry etched nano-structure sidewalls
- U – shape D_{it} distribution as in planar MOSFETs
- FGA reduces D_{it} everywhere while DE lowers D_{it} toward the valence band
- HfO_2 and Al_2O_3 give comparable results near CB, but rise of D_{it} toward VB stronger for HfO_2



- With all treatments, D_{it} level approaches level obtained on planar structures