Digital Etch for InGaSb p-Channel FinFETs with 10-nm Fin Width

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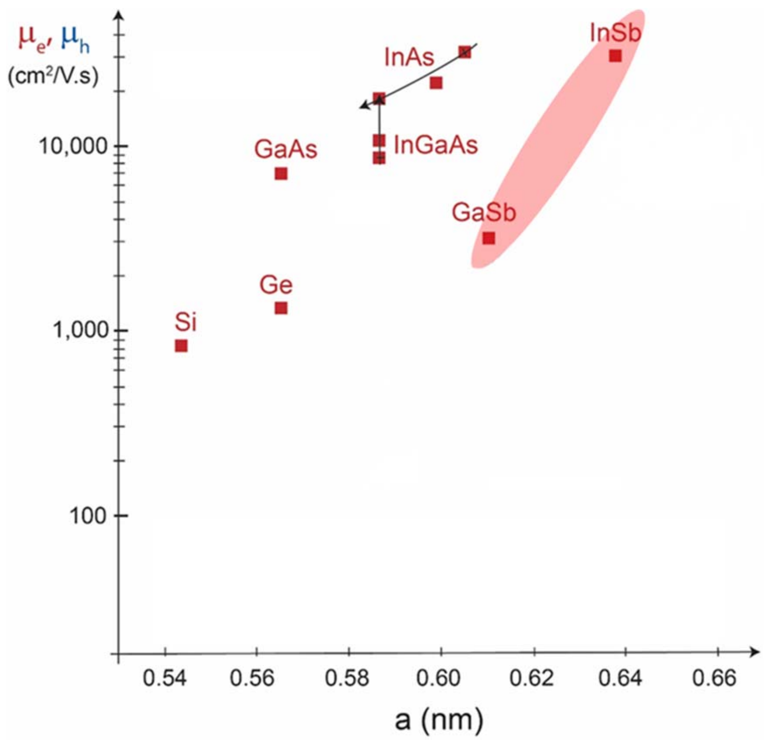
Outline

- Motivation
- InGaSb Digital Etch
- InGaSb p-channel FinFET
- Off-state Current
- Conclusions

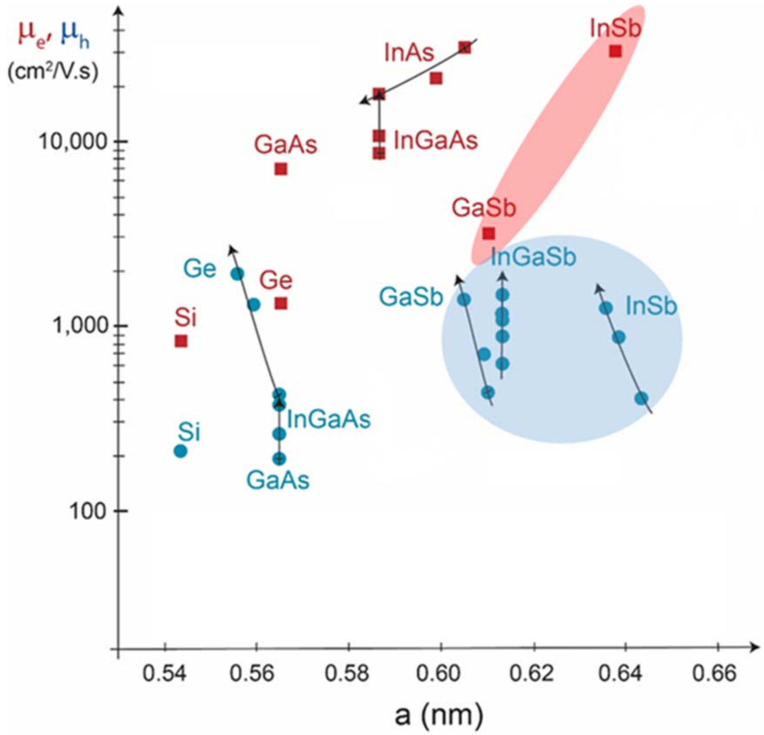
Reported Mobility in InGaSb

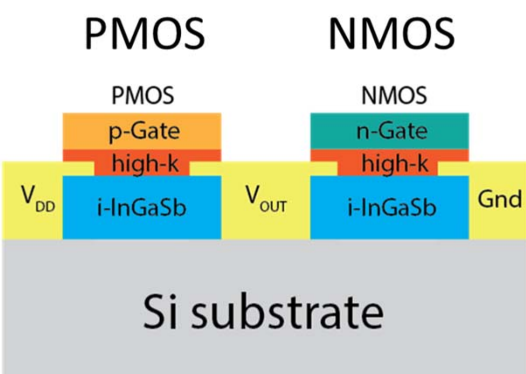


High electron mobility

del Alamo, Nature 2011

Reported Mobility in InGaSb





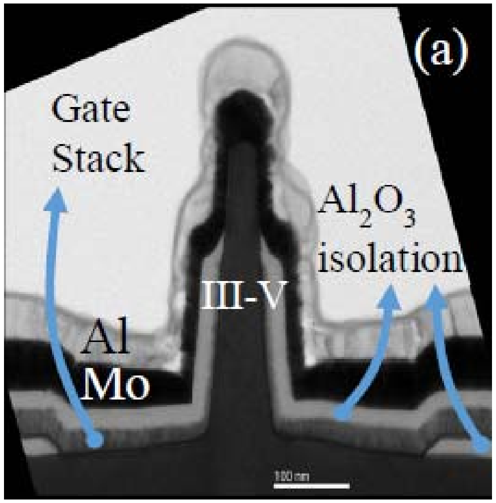
InGaSb CMOS

High hole mobility & strain effect

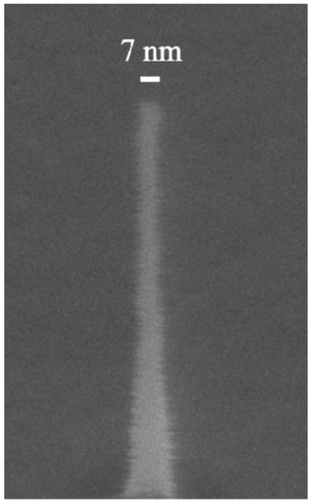
del Alamo, Nature 2011

Digital Etch

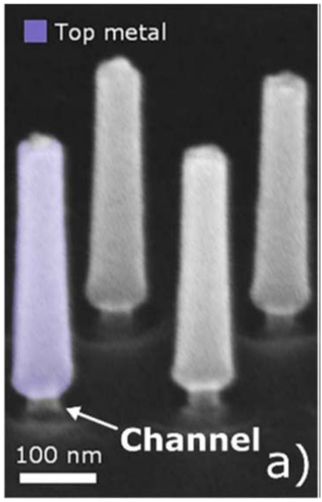
Ramesh, IEDM 2017



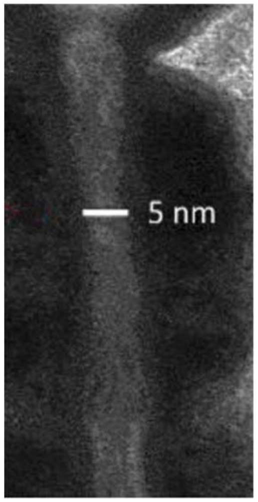
Zhao, IEDM 2017



Kilpi, IEDM 2017

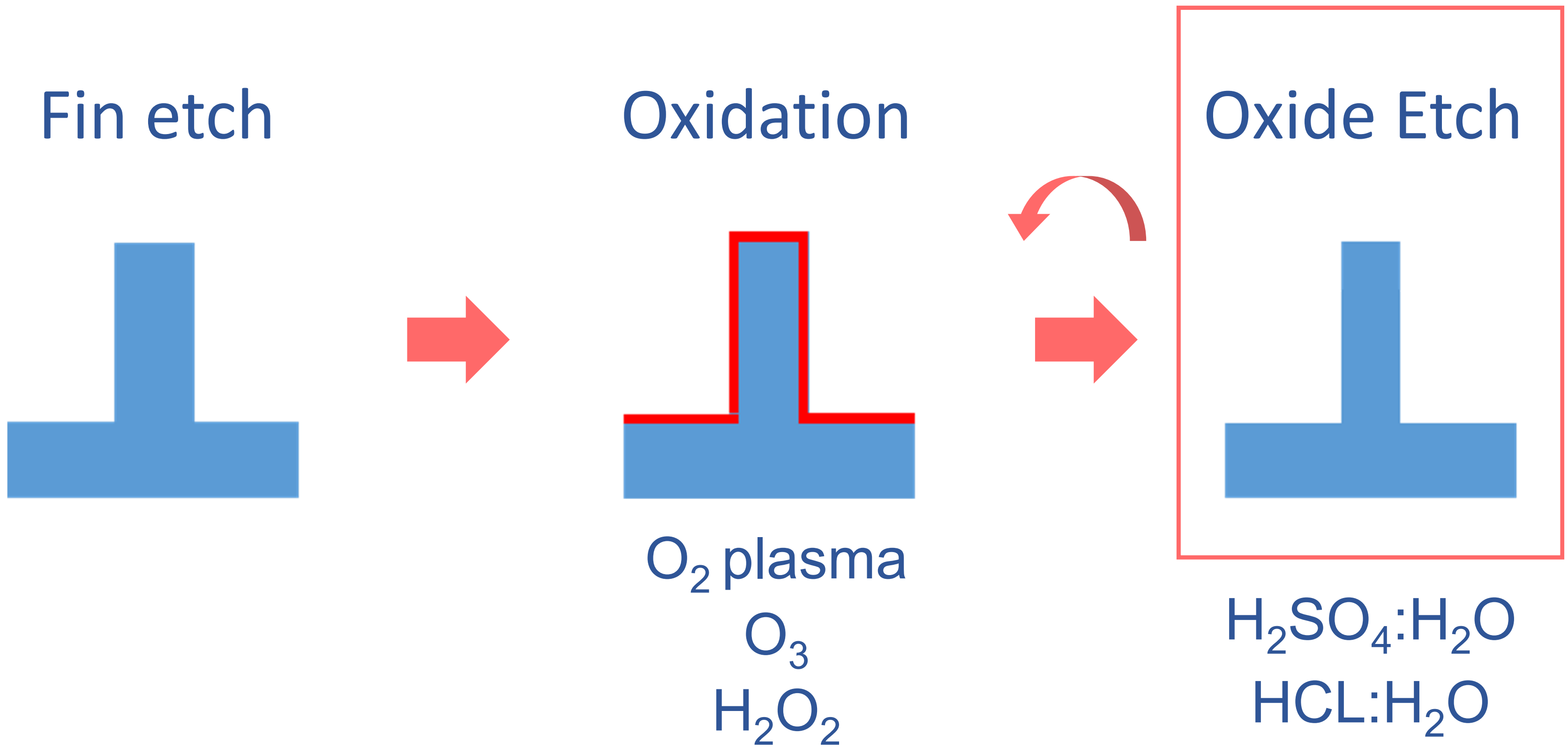


Vardi, IEDM 2017



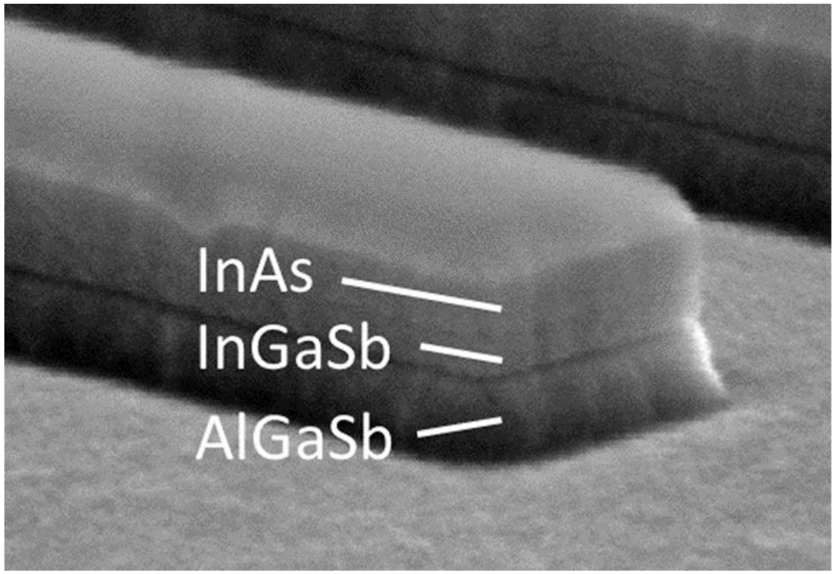
Digital Etch: standard in InGaAs VNW/FinFET process

Digital Etch in InGaSb



Key: Water Damages Antimonides

Dip in DI water for 2 min

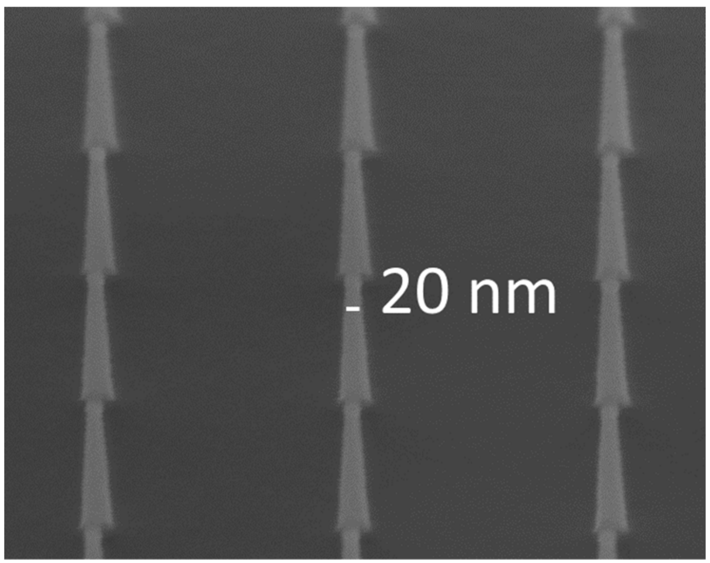


→ Must remove water

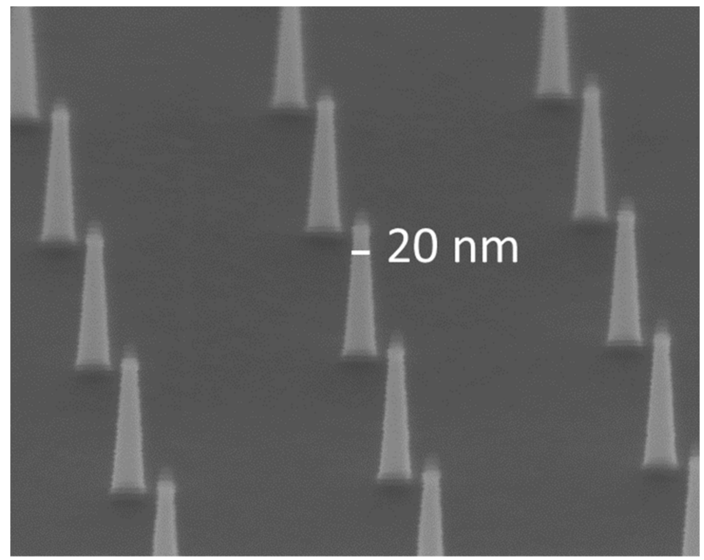
Lu, EDL 2017

Alcohol-based Treatment

After RIE



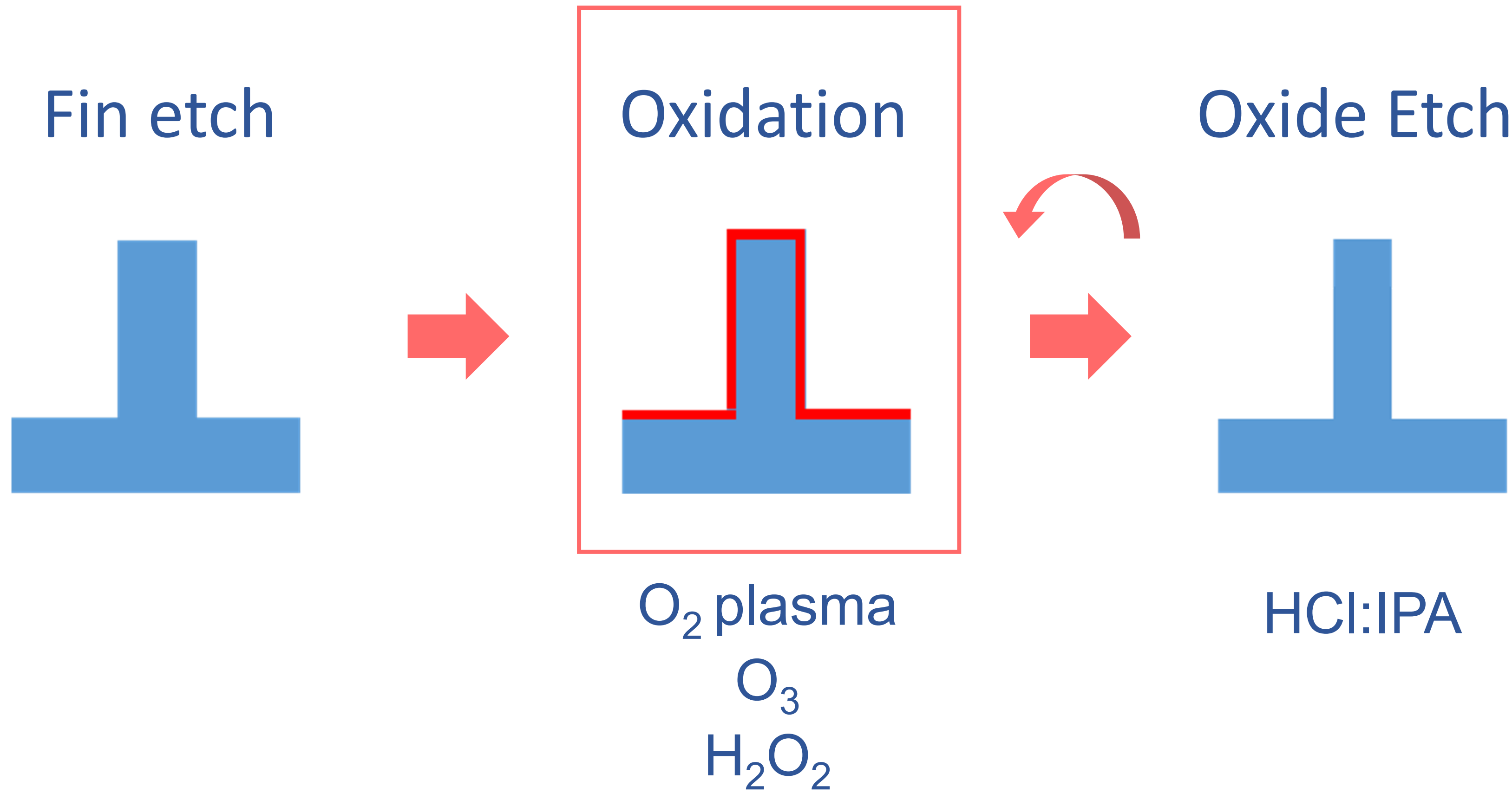
10% HCl:IPA 2 min



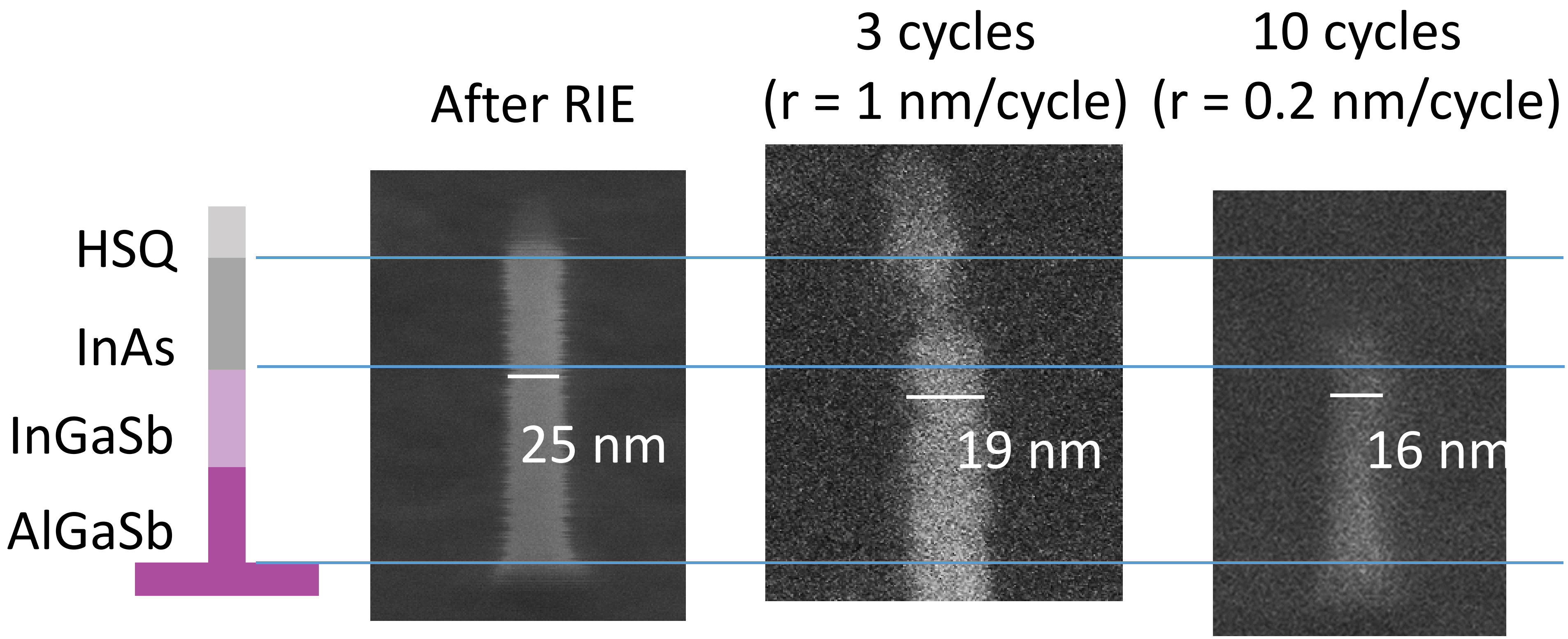
No sidewall damage

Lu, EDL 2017

Digital Etch in InGaSb



O_2 Plasma + HCl:IPA



r (III-Sb) ↓ after 3 cycles

r (III-As) > r (III-Sb)

Oxidation of GaSb

- In air:
  - Ga_2O_3, Sb_2O_3
- In strong oxidation agents:
  - Ga_2O_3, Sb_2O_3
  - Sb_2O_5 (insoluble in common aqueous acid/alkali)

Must avoid formation of Sb_2O_5

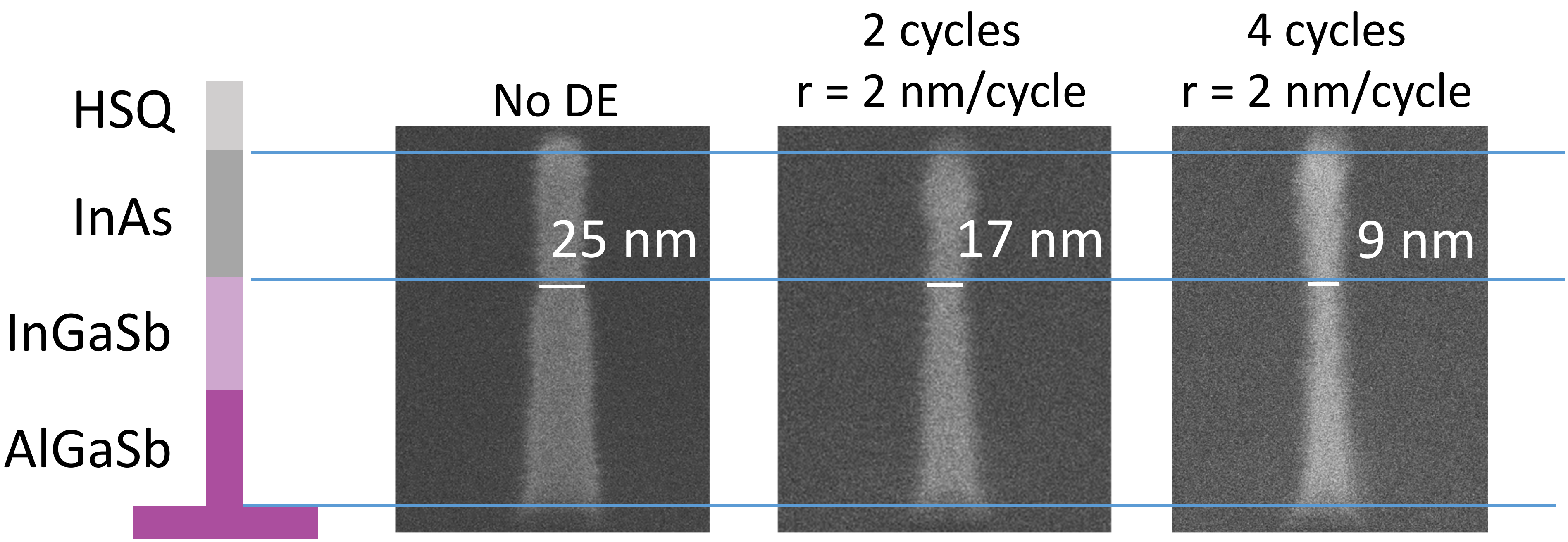
Liu, JVST B. 2002

Experiments of InGaSb DE

Oxide etch \ Oxidation	UV ozone	H_2O_2	Organic peroxides	O_2 plasma	RT O_2
H_2SO_4:methanol	Damage	Damage	Damage	Damage	Damage
Citric acid:IPA	No etching	No etching	No etching	No etching	No etching
Acetic acid:IPA	No etching	No etching	No etching	No etching	No etching
HCl:IPA	No etching	Rate $\rightarrow$ 0	Rate $\rightarrow$ 0	Rate $\rightarrow$ 0	2 nm/cycle

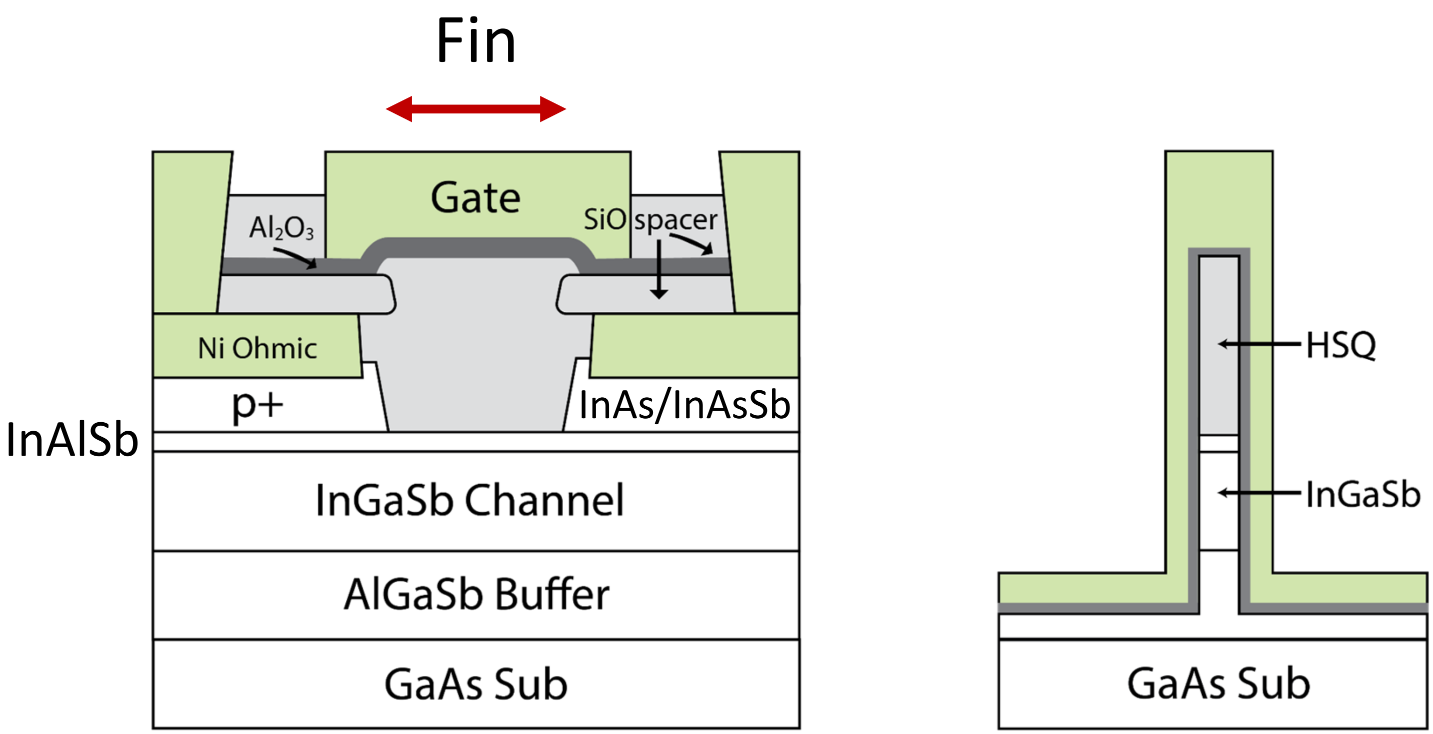
Best results: RT O_2 atmosphere + HCl:IPA

RT O_2 + HCl:IPA



- Stable etching rate
- Identical etch rate for InAs and antimonides

InGaSb p-Channel FinFETs

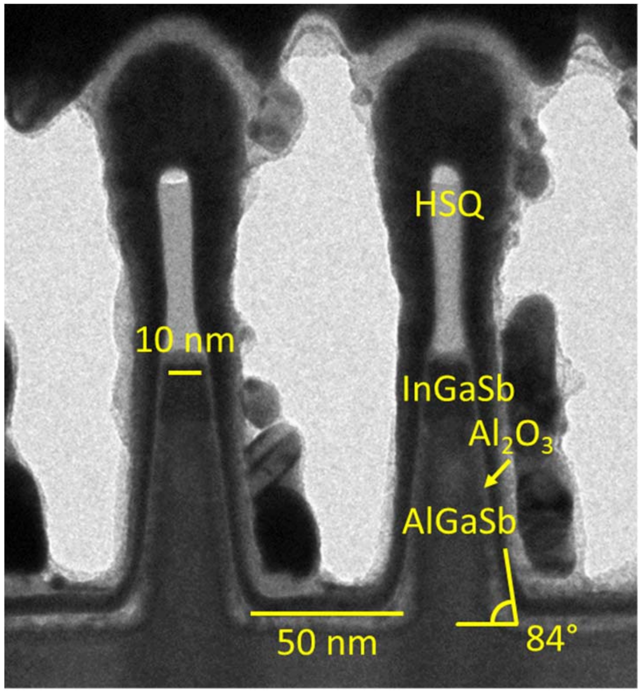


Heterostructure grown by KIST

InGaSb p-Channel FinFETs

- 3 Generations
  - G1: No sidewall treatment
  - G2: HCl:IPA treatment
  - G3: HCl:IPA + digital etch

G3 FinFET

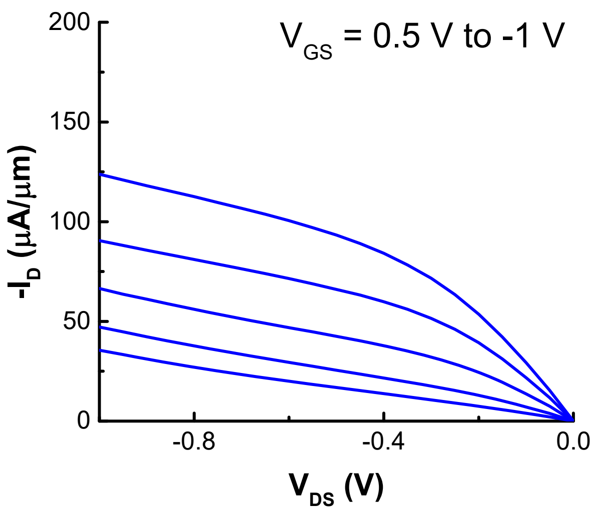


Minimum W_f = 10 nm

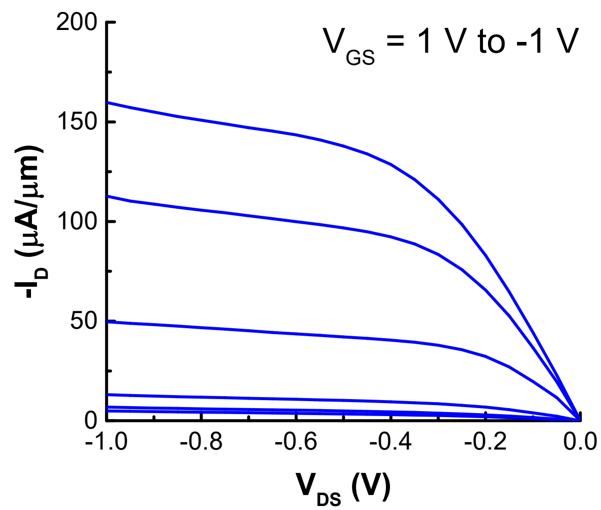
Lu, IEDM 2017

Minimum-size Devices

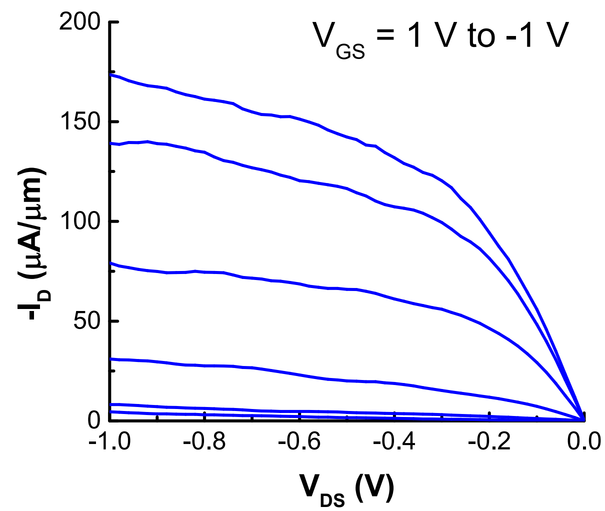
G1
W_f = 30 nm, L_g = 100 nm



G2
W_f = 18 nm, L_g = 20 nm



G3
W_f = 10 nm, L_g = 20 nm

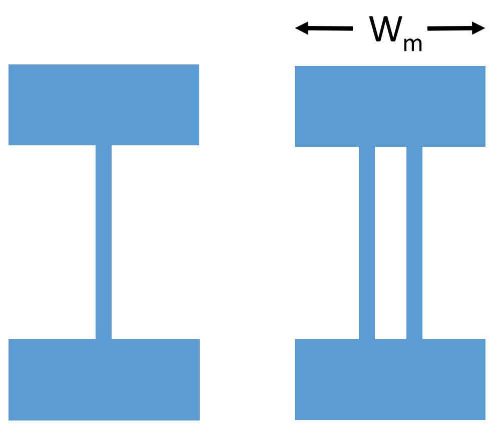


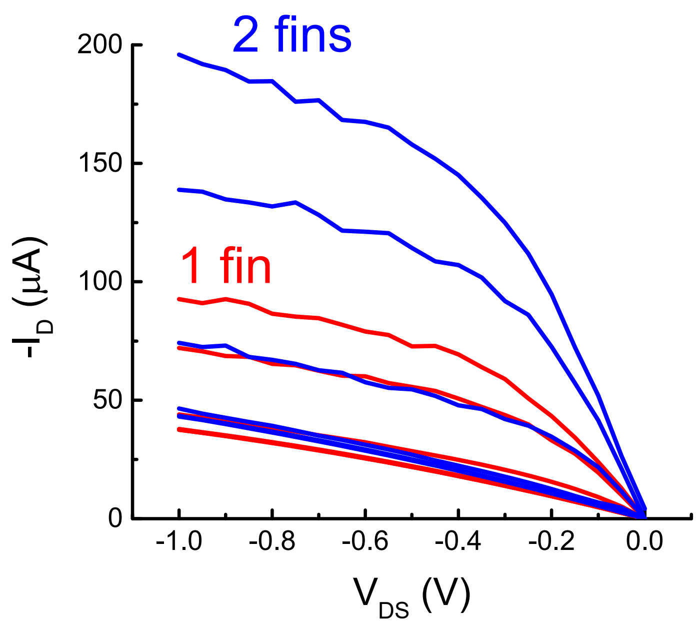
Lu, IEDM 2015
Lu, CSW 2017
Lu, IEDM 2017

Off-state Current

- G2: W_f = 20 nm, L_g = 100 nm

Same total mesa width

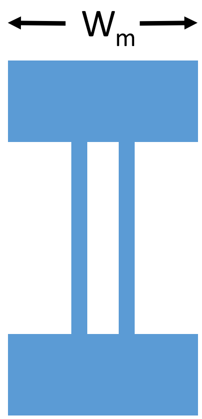


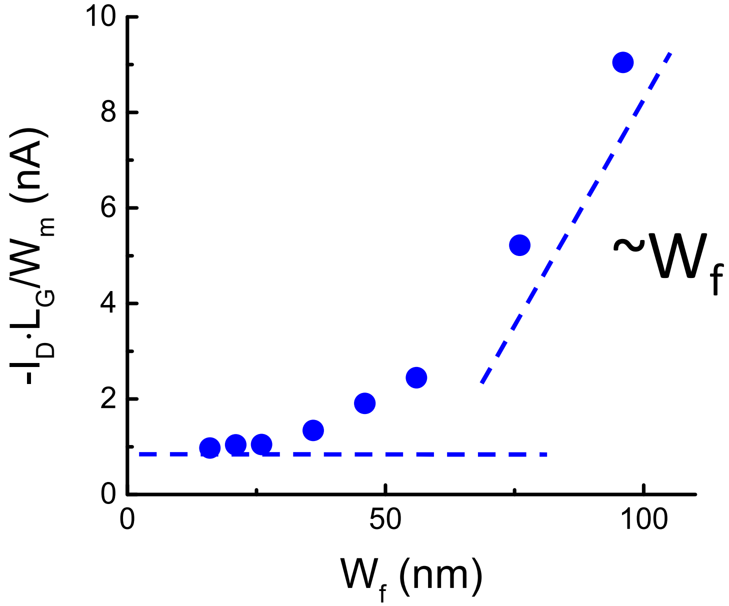


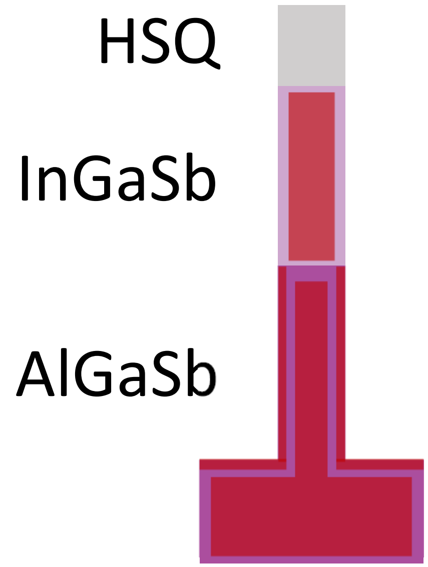
Presence of leakage paths outside the fins

Off-state Current

- G2: V_{gt} = 0.6 V, V_{ds} = - 50 mV

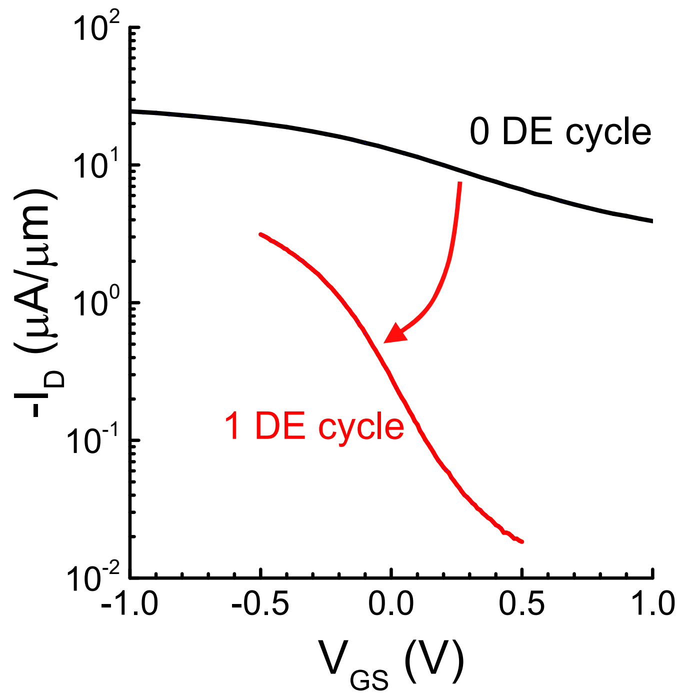






Off-state Current

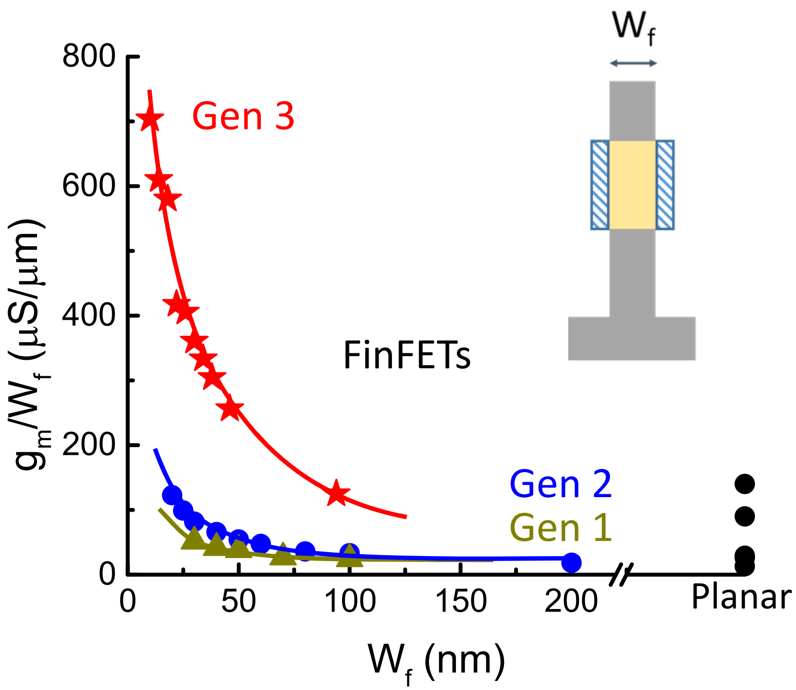
- G3: W_f = 20 nm, L_g = 1 µm, V_{DS} = -50 mV

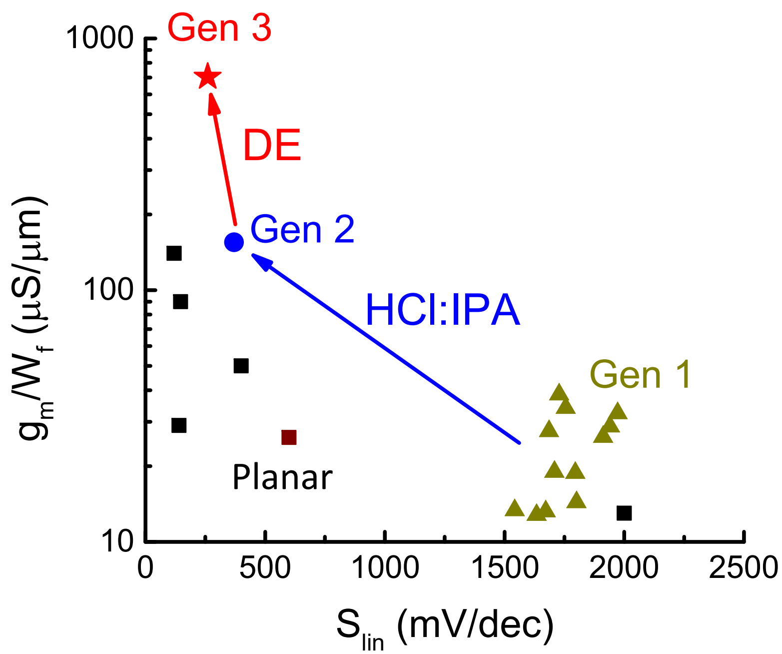


1 DE cycle significantly improves off current

More improvement needed

Benchmark





g_m/W_f = 704 µS/µm at W_f = 10 nm

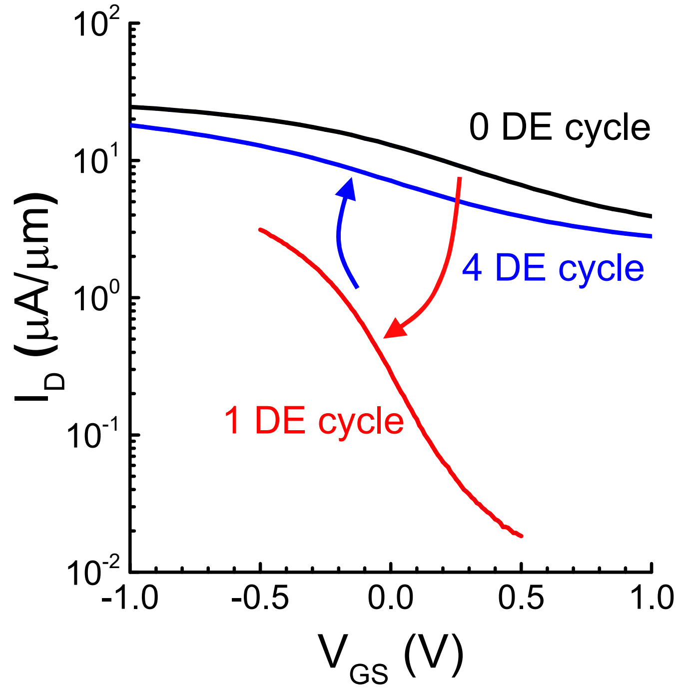
Conclusion

- Digital Etch
  - Alcohol-based HCl treatment
  - O_2 for oxidation at RT
  - Compatible to InGaSb and InAs

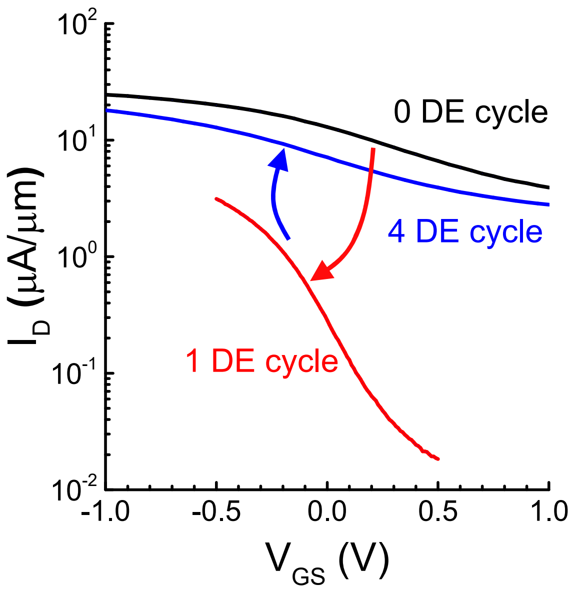
- InGaSb p-Channel FinFETs
  - Minimum W_f = 10 nm, L_g = 20 nm
  - HCl:IPA and DE improves I_{off}
  - Record device performance

Off-state Current

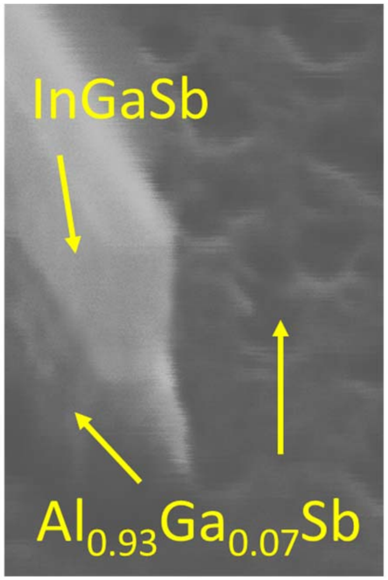
- G3: W_f = 20 nm, L_g = 1 μm, V_{DS} = -50 mV



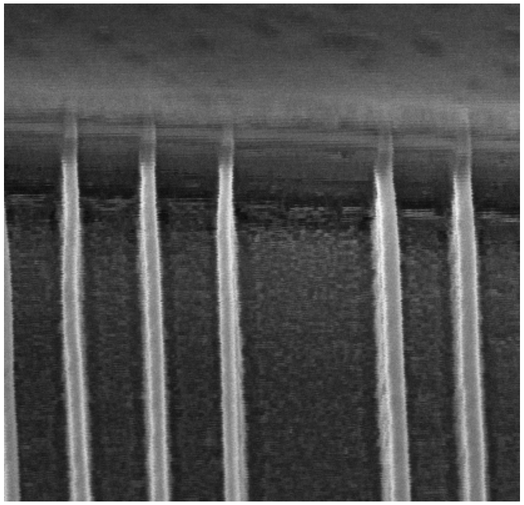
Off-state Current



3 DE cycle



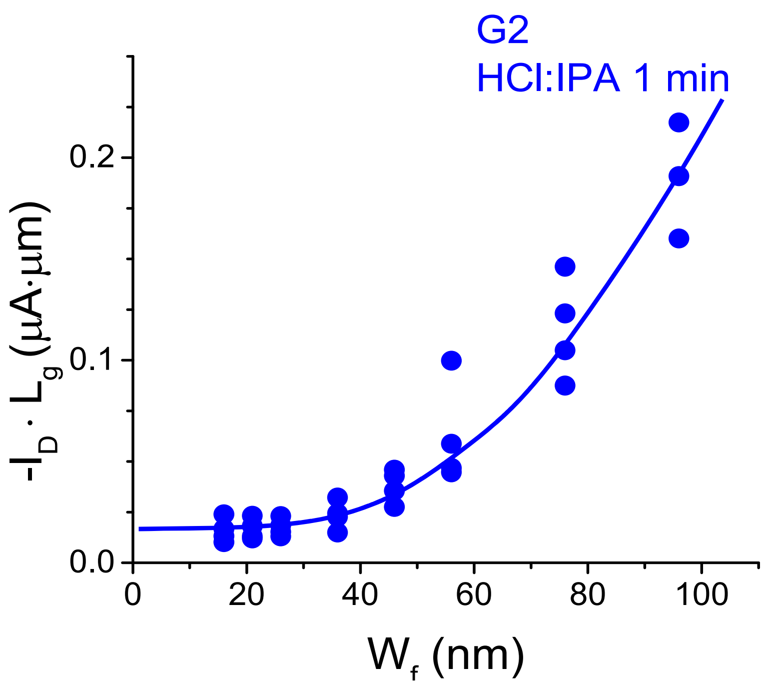
10 min air exposure

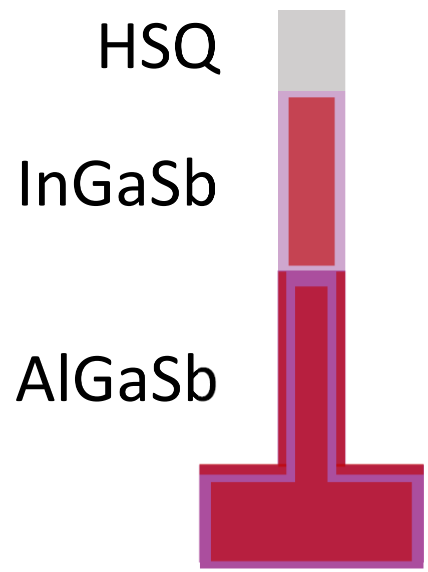


- Buffer is damaged after multiple DE cycles
  - $Al_{0.93}Ga_{0.07}Sb$ is too reactive

Off-state Current

- G2: V_{gt} = 0.6 V, V_{ds} = - 50 mV

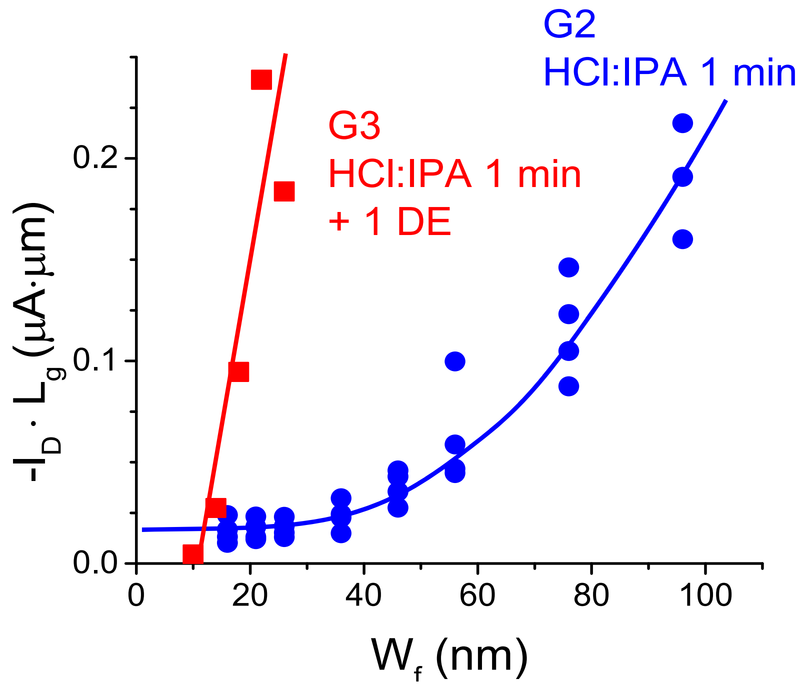




HCl:IPA → Super-linear dependency on W_f

Off-state Current

- G3: V_{gt} = 0.6 V, V_{ds} = - 50 mV



+ 1 DE → More linear dependency on W_f