

TU1A-1

Back-gate lumped resistance effect on AC characteristics of FD-SOI MOSFET

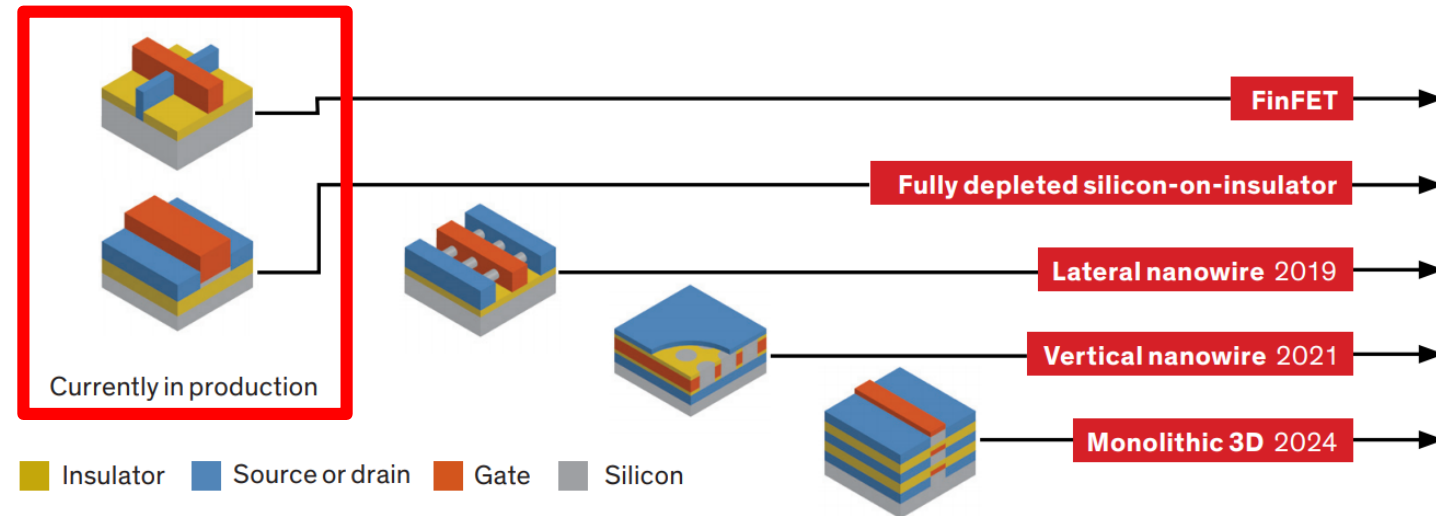
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- Introduction – UTBB FD-SOI
- Self-Heating (SHE)
- Output conductance measurements
- Back-Gate/substrate modeling
- Conclusion

Introduction

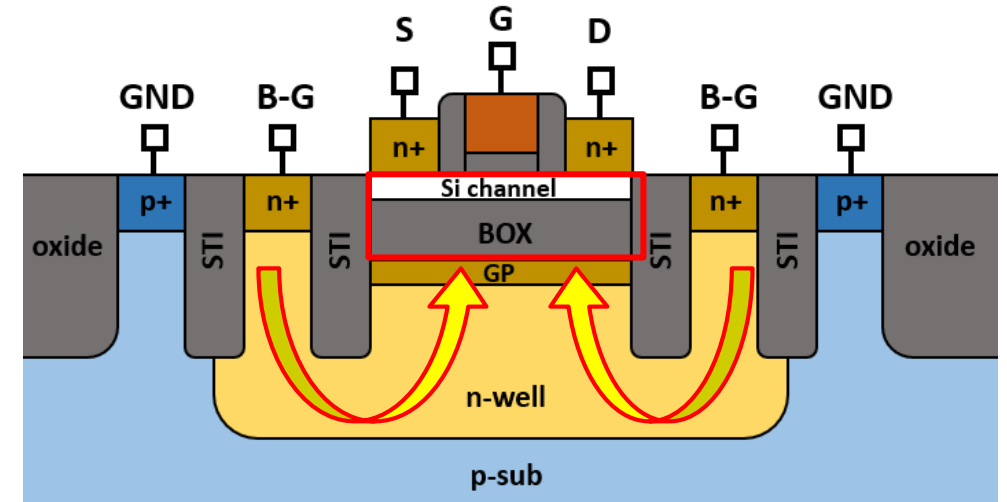
- Device downscaling is accompanied by introduction of
 - New materials
 - New architectures
- Two main contenders:
 - UTBB FD-SOI
 - MuGFET



2016 IEEE Spectrum 53(9):9-11

UTBB FD-SOI

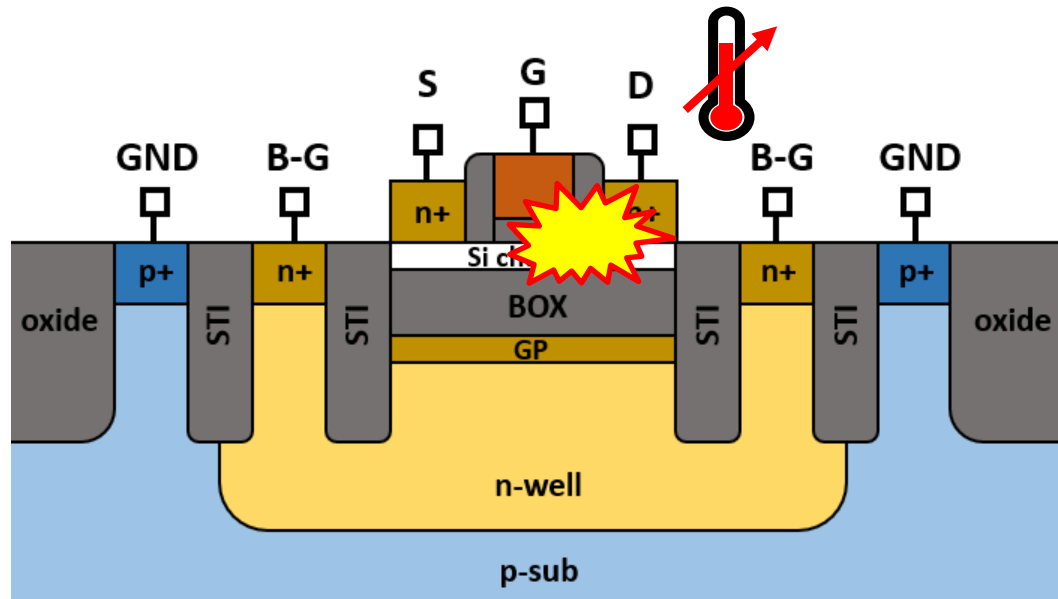
- Thin Si film and buried oxide (BOX)
- Excellent variability control
- Very good control of short channel effects
- Tunability of electrical performance
- Very good digital, analog and RF performance



➔ FD-SOI is foreseen as a competitive technology platform for low power wireless applications, IoT, 5G,...

Self-Heating Effect (SHE)

- Higher current density due to aggressive downscaling
- Reduction of thermal conductivity with gate length and film thicknesses reduction
- Low thermal conductivity of SiO_2 buried oxide (BOX)

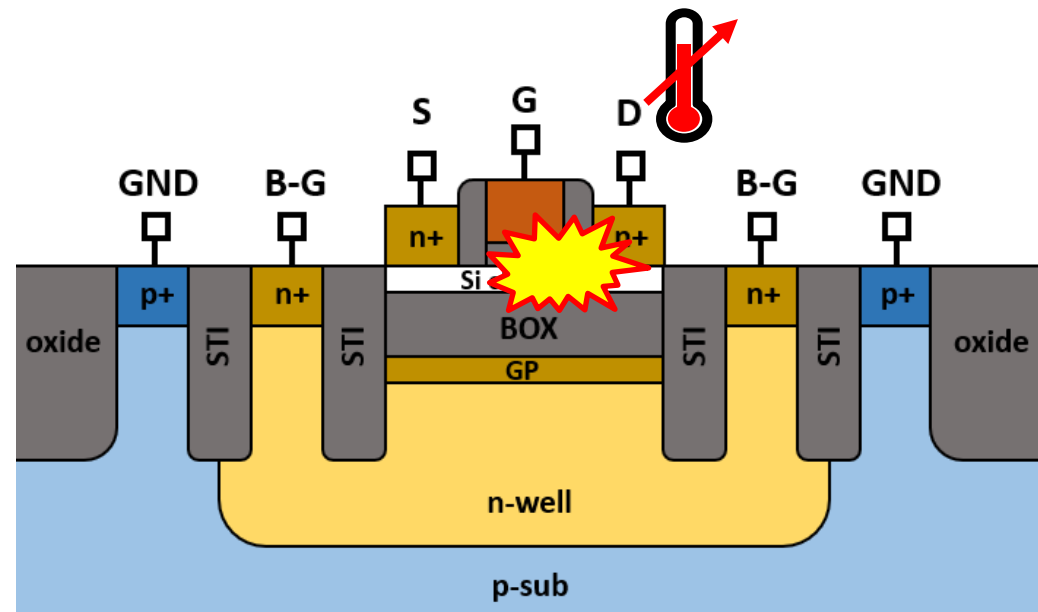


➔ Channel temperature rise

Self-Heating Effect (SHE)

- Temperature rise of 87 K in FD-SOI in 28 nm FETS at $V_g = V_d = 1$ V in [1]
- Effects:
 - Degraded device performance
 - Mobility reduction
 - Lower output current
 - Reliability issues
 - V_{TH} shift

At higher V_g bias



➔ Need characterization and extraction techniques in order to properly model SH

[1] S. Makovejev et al., *Solid-State Electronics* 2016.

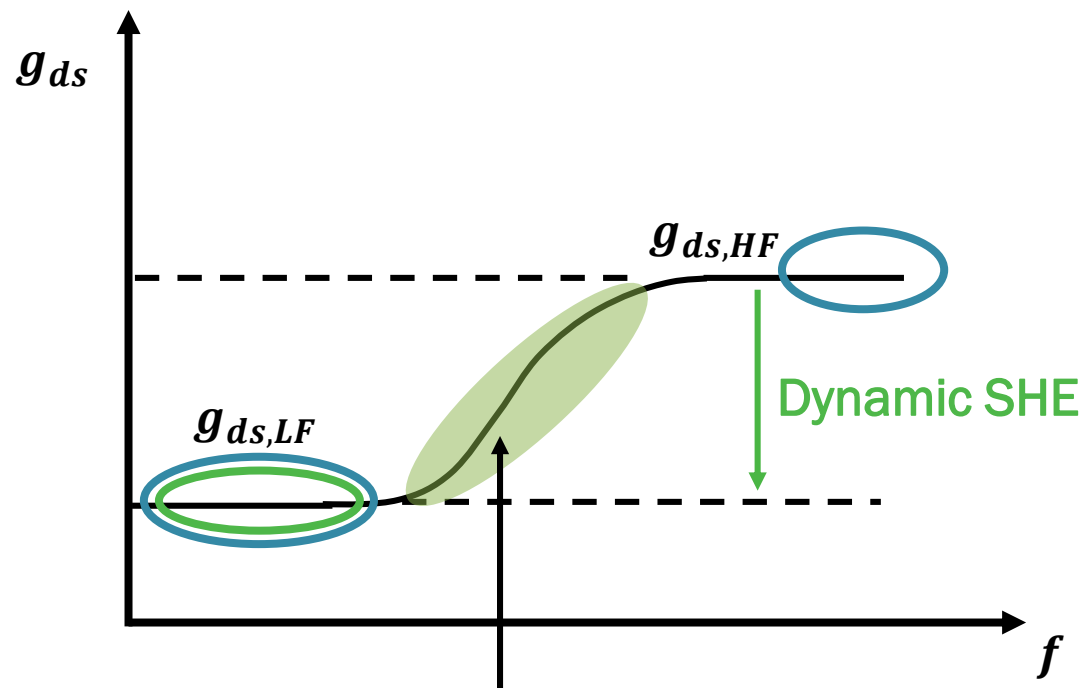
Self-Heating Effect (SHE)

Effect apparent in the Y-parameters

→ Output conductance $g_{ds} = \Re\{Y_{21}\}$

Low frequency

- g_{ds} with **static** and **dynamic** SHE



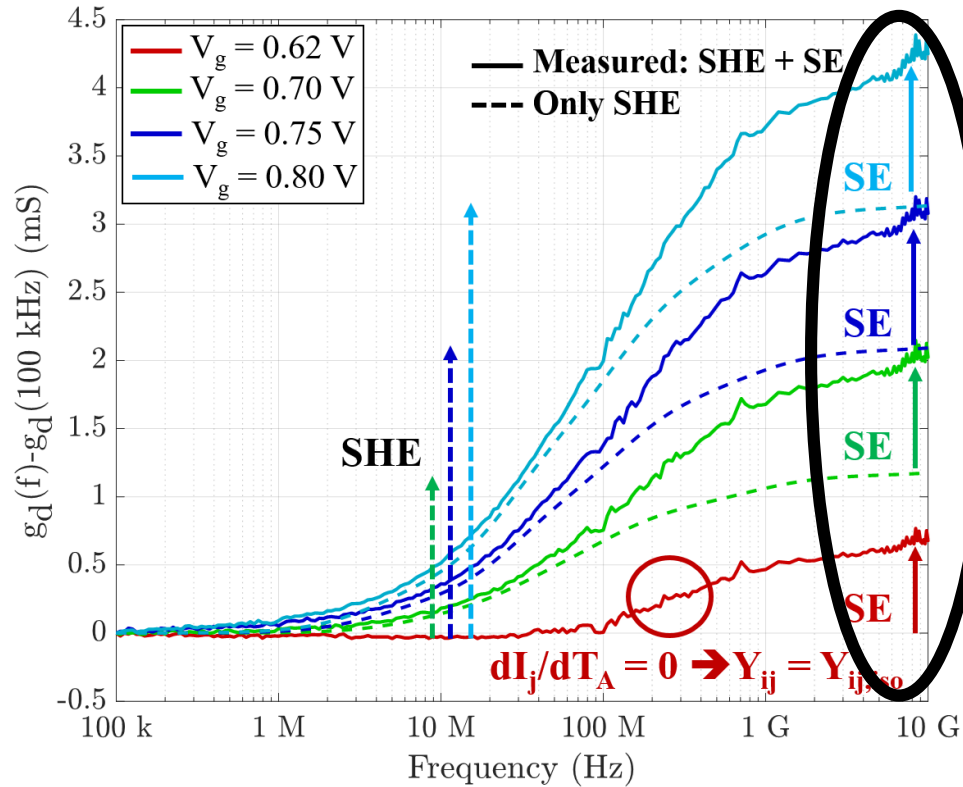
High frequency

- g_{ds} with **static** SHE
- No **dynamic** SHE because temperature cannot follow HF signal

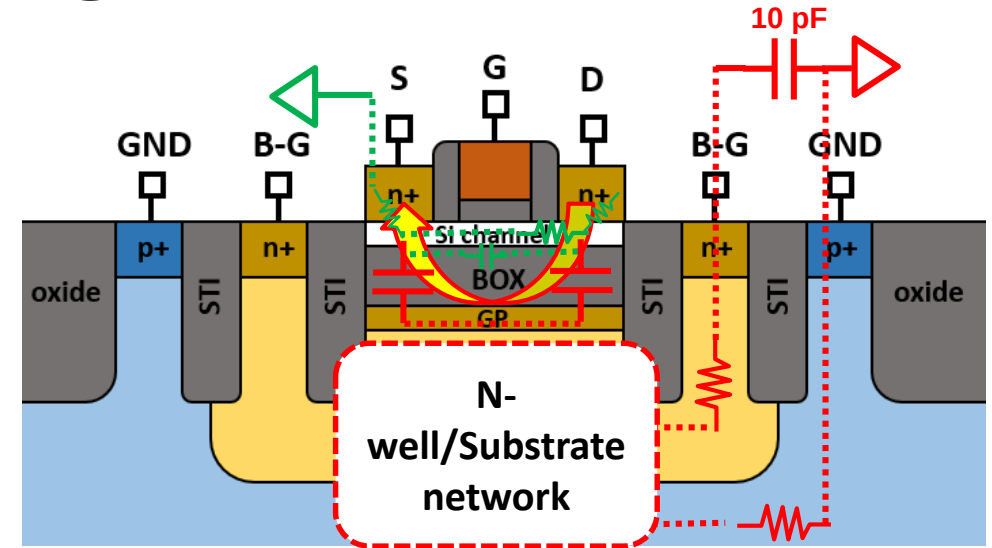
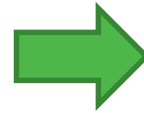
f_{SH} shifts to higher frequency for advanced architectures (with small volumes) from 10-100 kHz in previous nodes to **10-100 MHz - 1 GHz** in advanced technologies

Self-Heating Effect (SHE)

Extraction of self-heating is not straightforward



Substrate
effect
(SE)

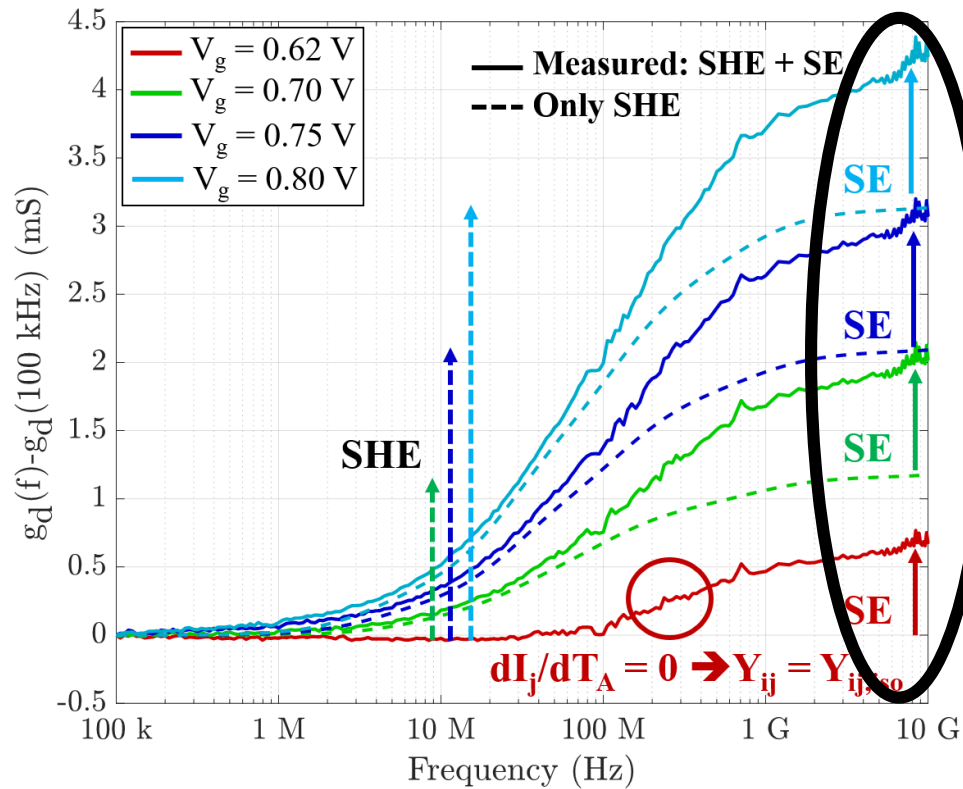


- Coupling between source and drain through BOX
- Complex back-gate/substrate network

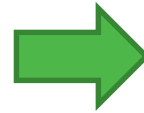
L. Nyssens et al., *VLSI-TSA 2021*.

Self-Heating Effect (SHE)

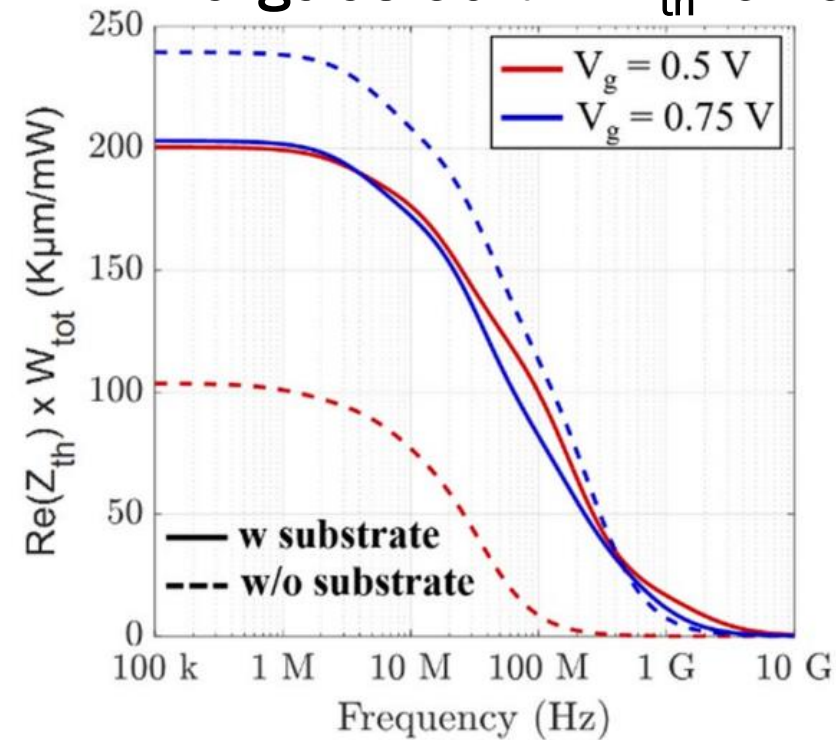
Extraction of self-heating is not straightforward



Substrate
effect
(SE)



- Same frequency range as SHE
- Neglecting SE can lead to an error as large as 60% in R_{th} for low- V_g range

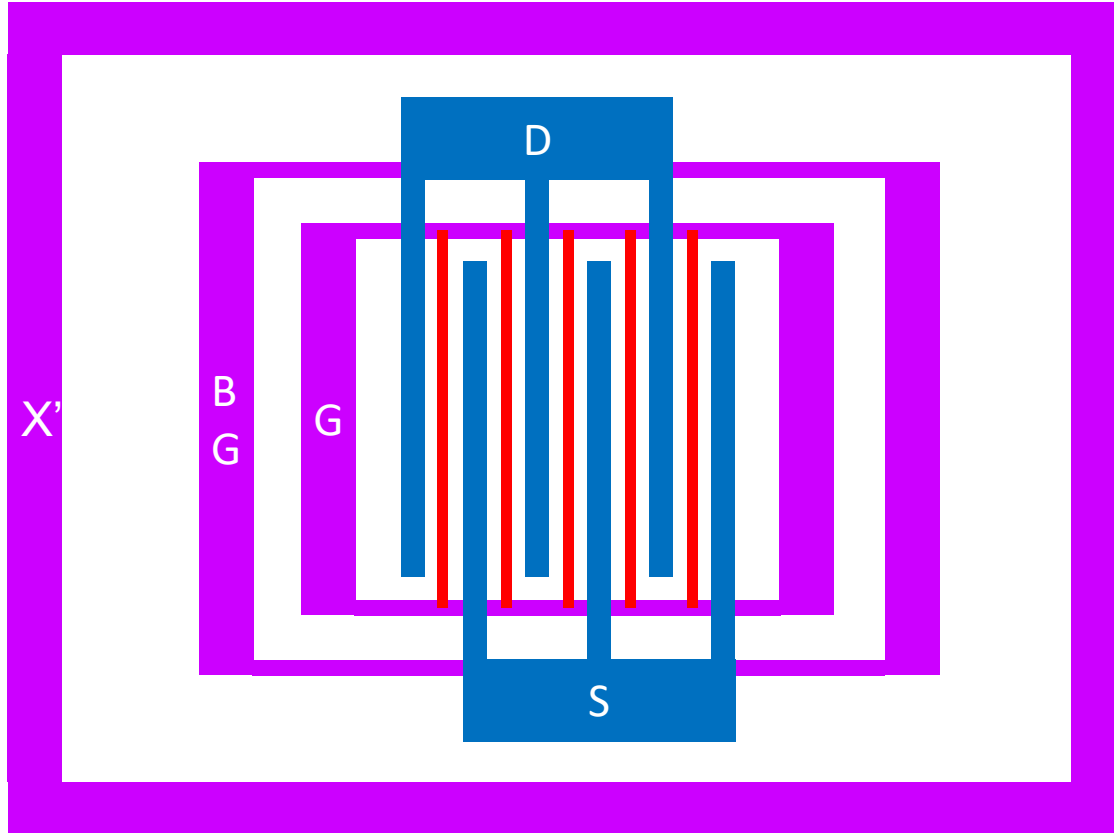


L. Nyssens et al., *VLSI-TSA 2021*.

L. Nyssens et al.,
IEEE EDL 2021.

Back-Gate/substrate modeling

Layout

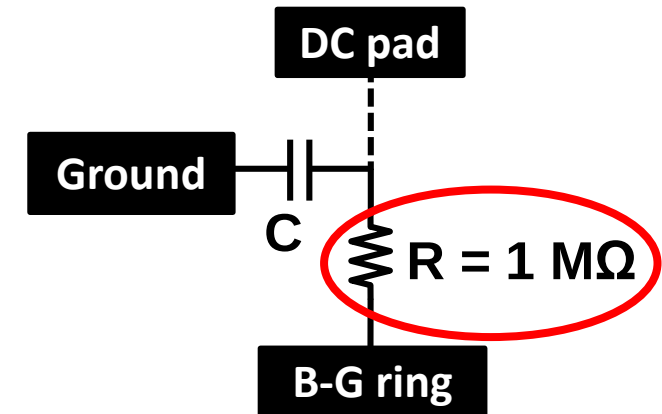
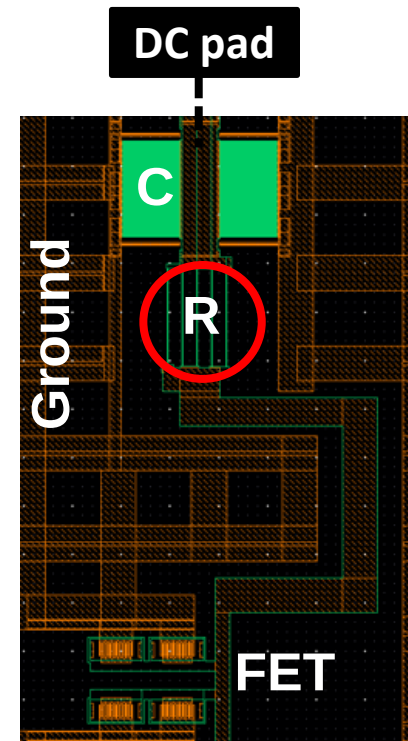
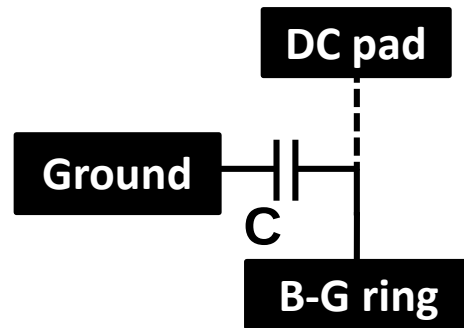
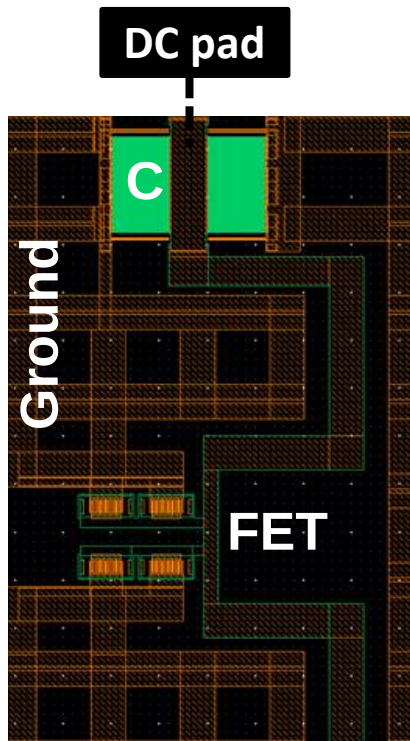


Dimensions

- $L_g = 20 \text{ nm}$
- $W_f = 0.5 \mu\text{m}$
- $N_f = 16$
- $N_{vf} = 2$
- Multiplicity = 4

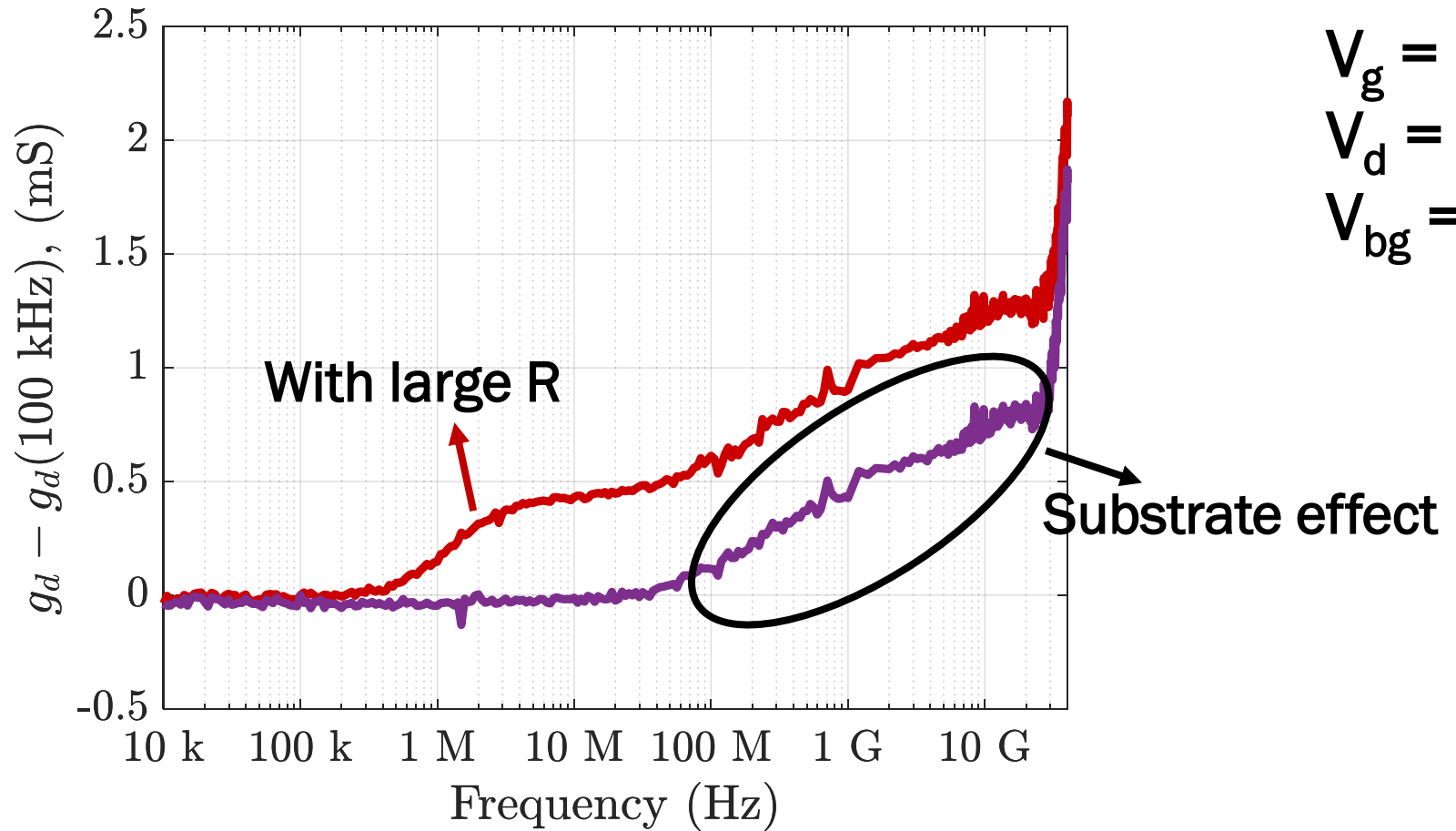
Back-Gate/substrate modeling

Two devices with different back gate connections



Back-Gate/substrate modeling

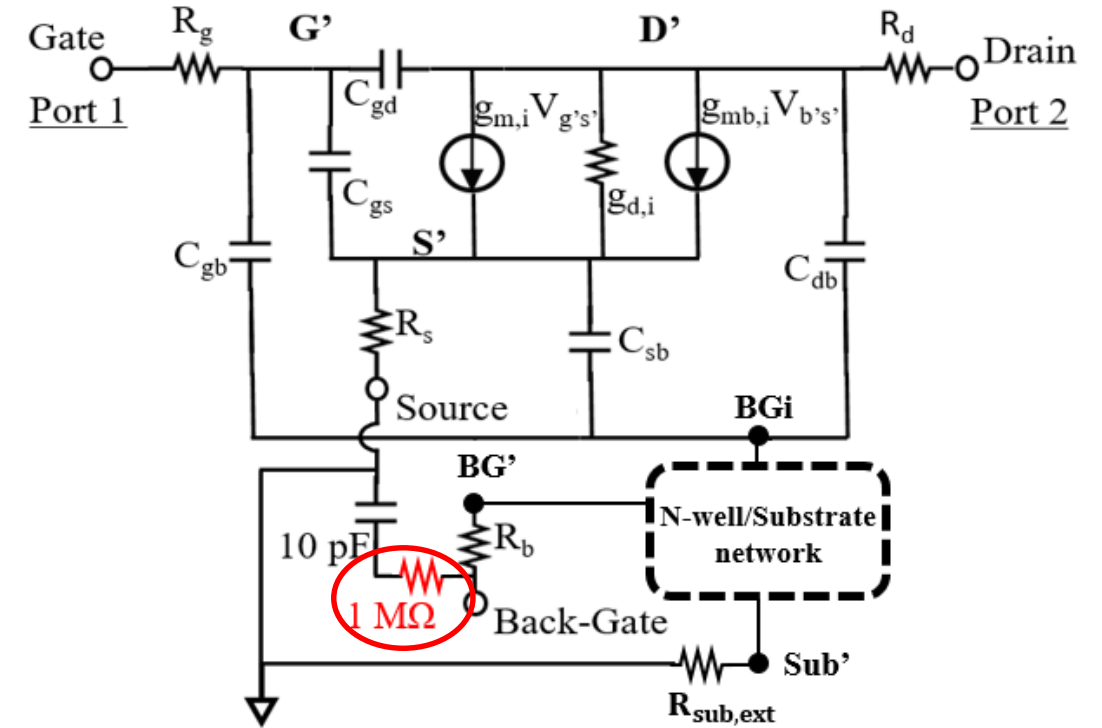
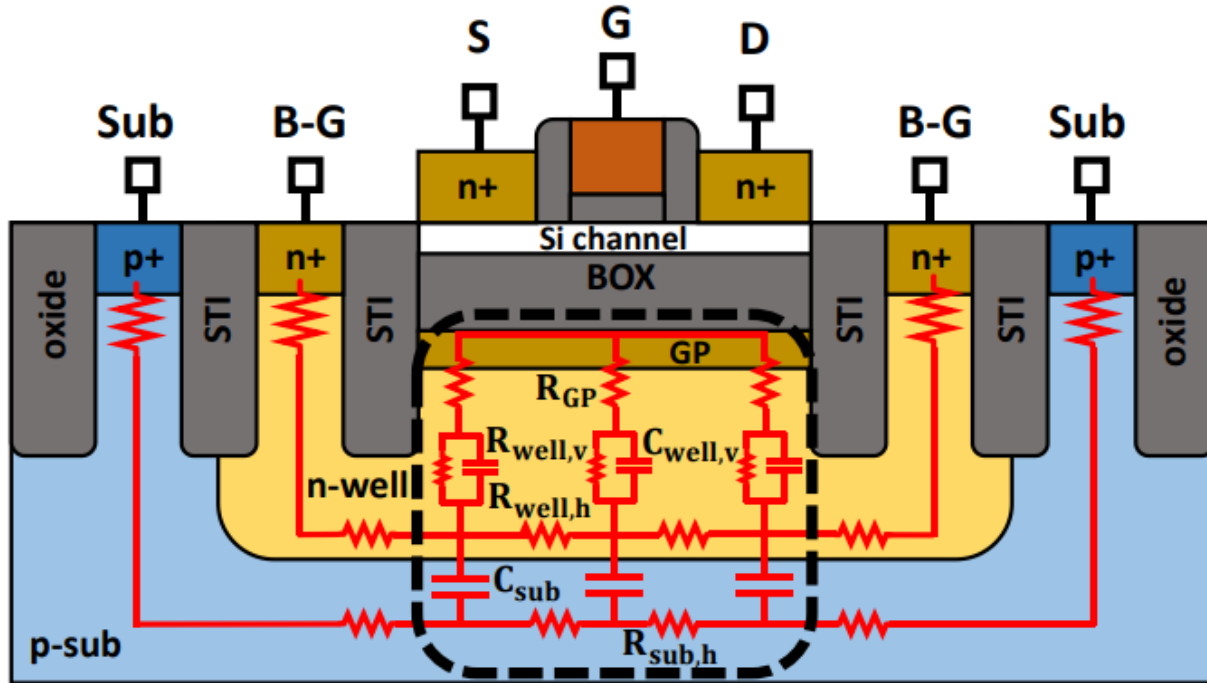
Output conductance $g_{ds} = \Re\{Y_{21}\}$



$V_g = 0.62 \text{ V}$
 $V_d = 0.8 \text{ V}$
 $V_{bg} = 0 \text{ V}$

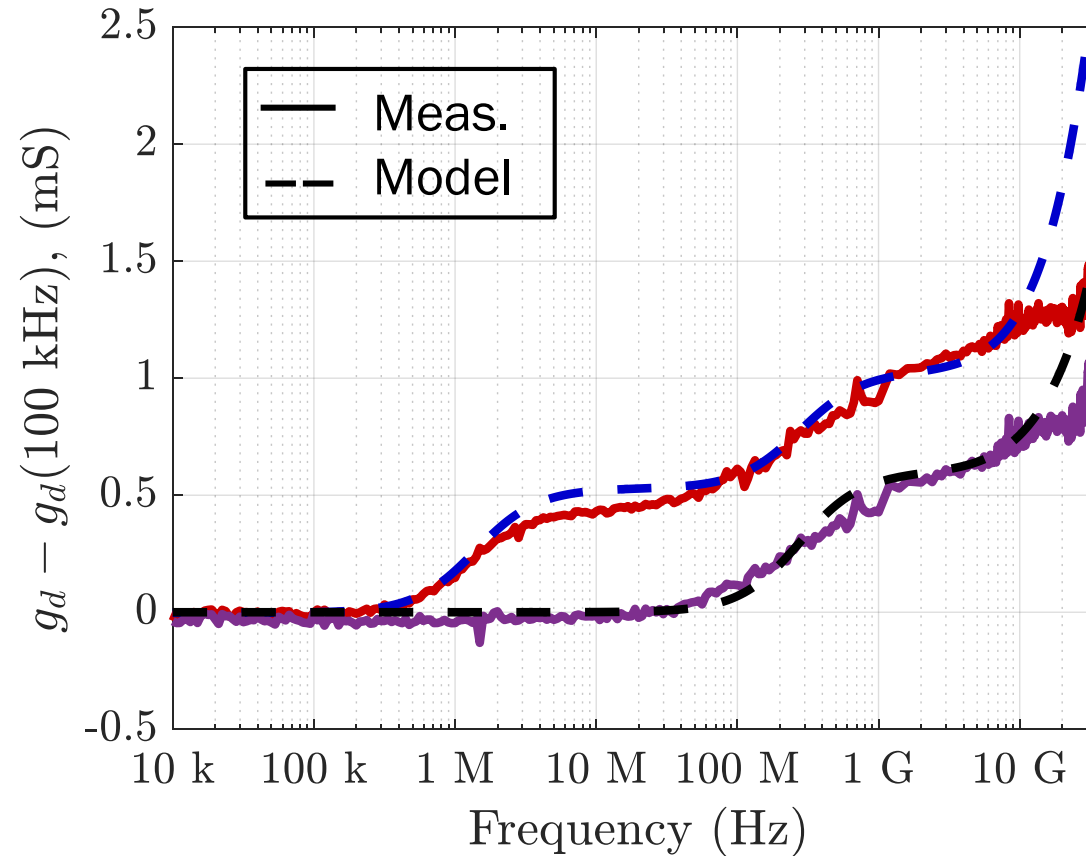
Back-Gate/substrate modeling

Small-signal equivalent circuit



Back-Gate/substrate modeling

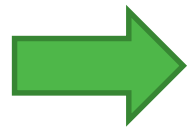
Output conductance $g_{ds} = \Re\{Y_{21}\}$



$V_g = 0.62 \text{ V}$
 $V_d = 0.8 \text{ V}$
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Conclusions

- Connecting the back-gate via a large lumped resistor creates an additional transition in the measured output conductance.
- Substrate effect related transition also appears in the measured output conductance.



Calls for accurate compact models capturing not only intrinsic elements but also second order effects relative to the back-gate and substrate.