UNIVERSITY OF CALIFORNIA SANTA BARBARA
ELECTRICAL AND COMPUTER ENGINEERING

Self-Aligned InGaAs Channel MOS-HEMTs for High Frequency Applications

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Advisor: Prof. Mark Rodwell

Funding: SRC & DARPA

SRC® JUMP Joint University Microelectronics Program

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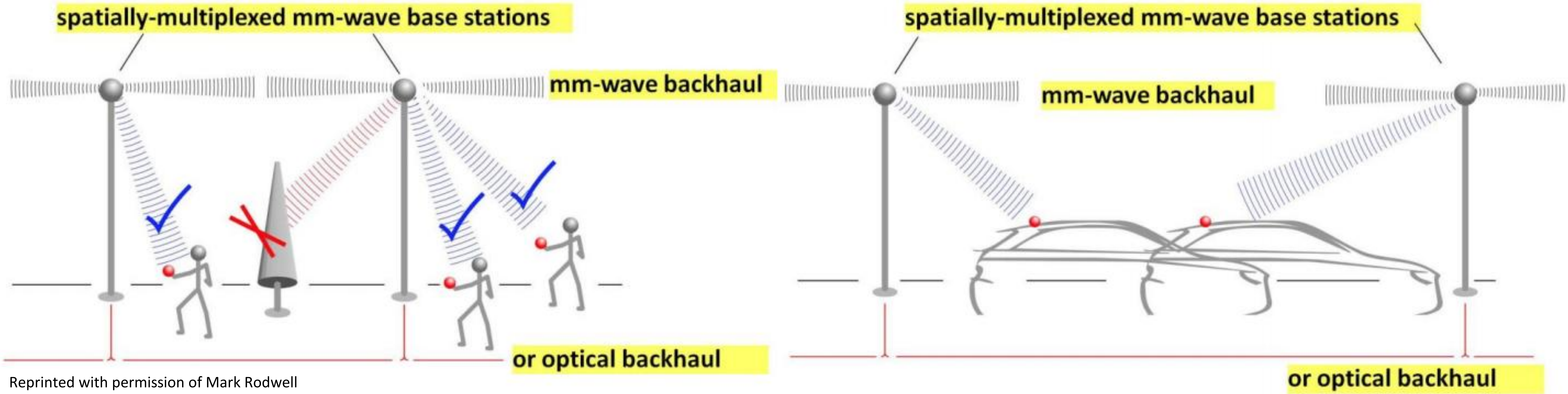
Motivation – Beyond 5G



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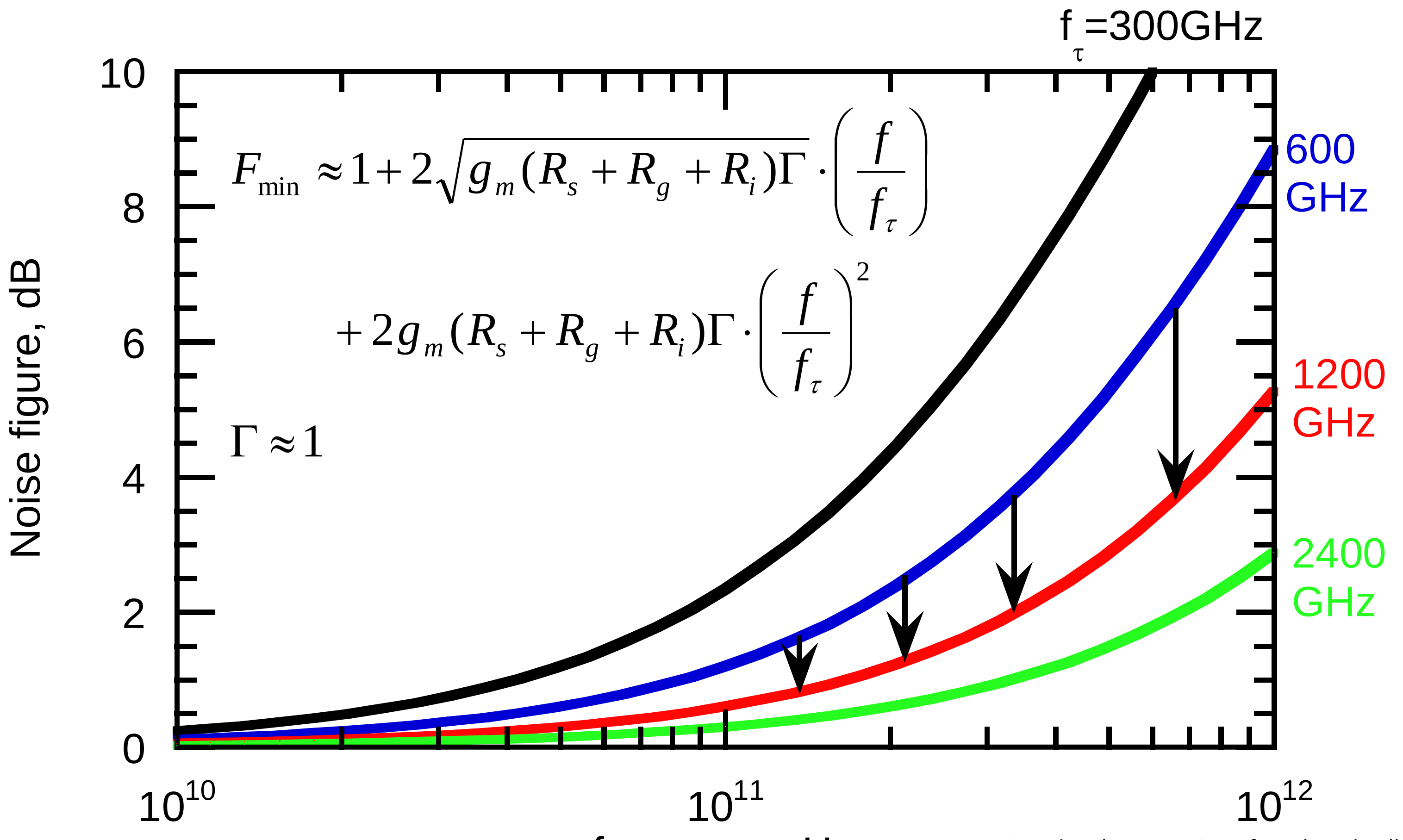
- Industry currently introducing 5G (20-80 GHz)
- Beyond 5G requires 100-300 GHz communication systems
  - More bandwidth
  - Higher data rates
- Requires transistors operate "easily" at these frequencies:

FETs – Reduce Noise Figure

- Increase in f_τ :
- Current frequency
  - Improved noise
- higher-frequency systems
  - Same noise



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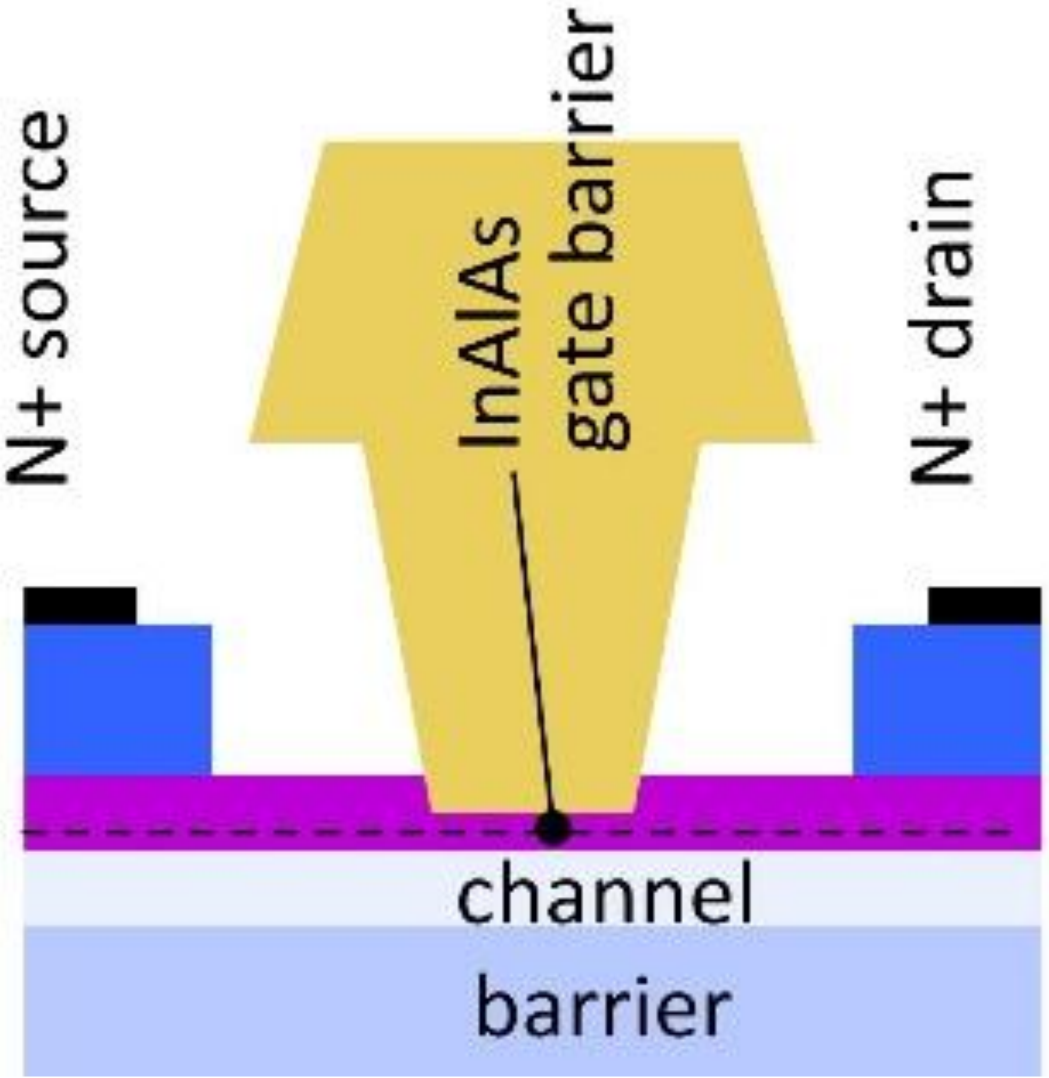
Why not HEMT?

$$f_\tau \approx \frac{g_{m,e}}{2\pi(C_{gs} + C_{gd})}$$

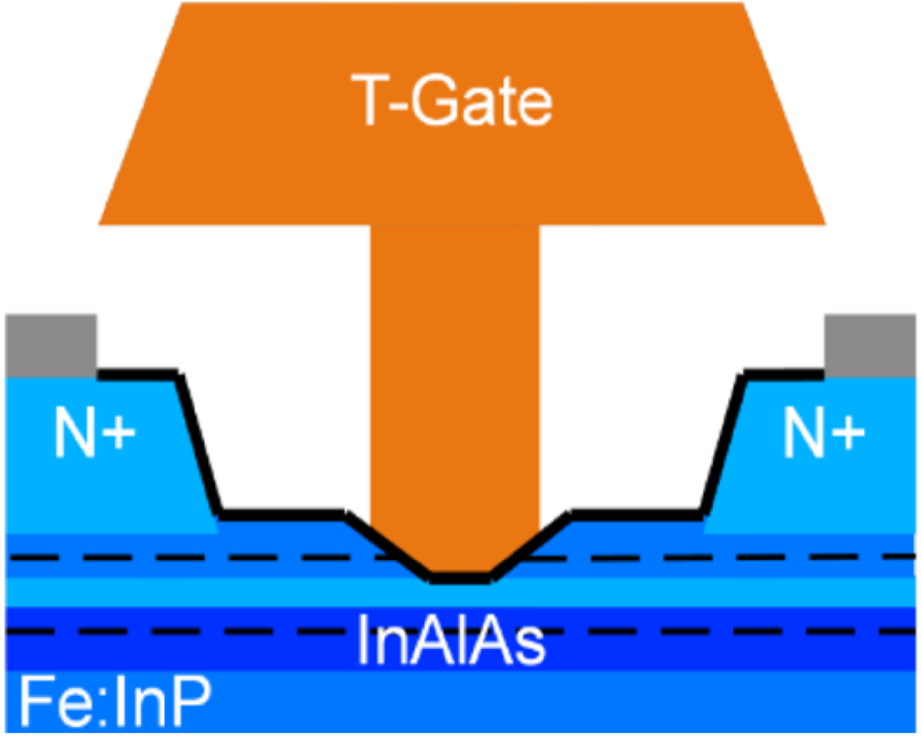
- Increasing f_τ by reducing $C_{GS,i}$
- Reduced C_{GS} / C_{GD} hurts g_{ds}
- Scaling laws say thin gate insulator
- InAlAs – InGaAs CBO ~ 0.5 eV
- High gate leakage



MOS-HEMTs

Institution	L_g (nm)	$g_{m,e}$ (mS/µm)	$g_{ds,e}$ (mS/µm)	C_{GS} (fF/um)	C_{GD} (fF/um)	f_τ (GHz)	f_{max} (GHz)
Markman *et al.*	40	2.9	0.15	0.8	0.2	403	594

- Add gate dielectric
- Improve C_{GS} /C_{GD}
- Improve g_{ds}



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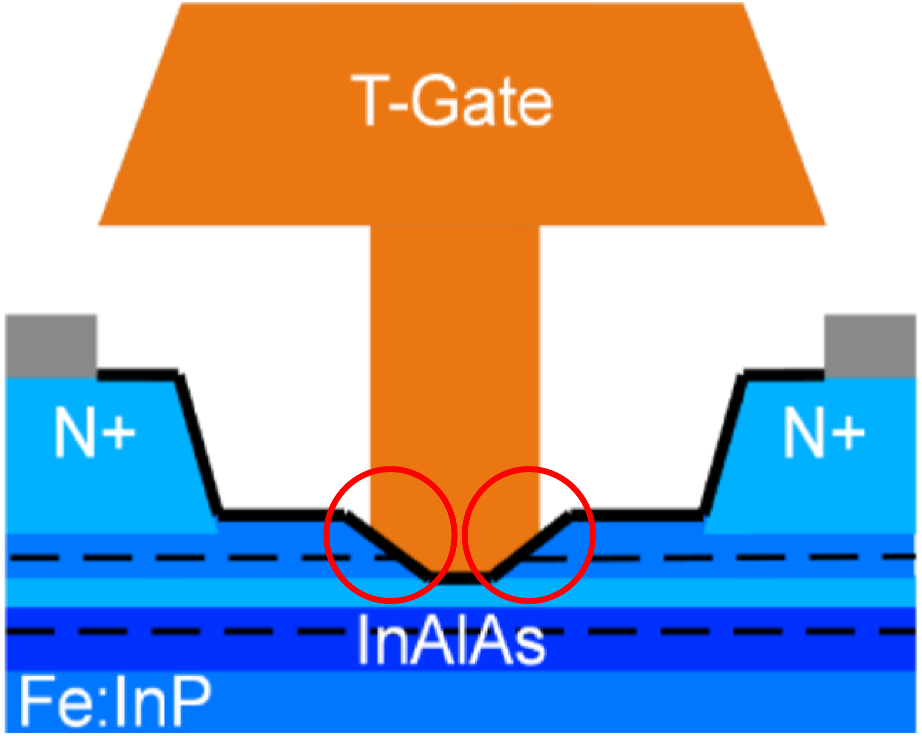
- Ft, fmax limited by CGS, CGD
- Fringe capacitance from gate-link overlap
  - T-gate filling
  - Gate alignment
- Extra capacitance from thick link



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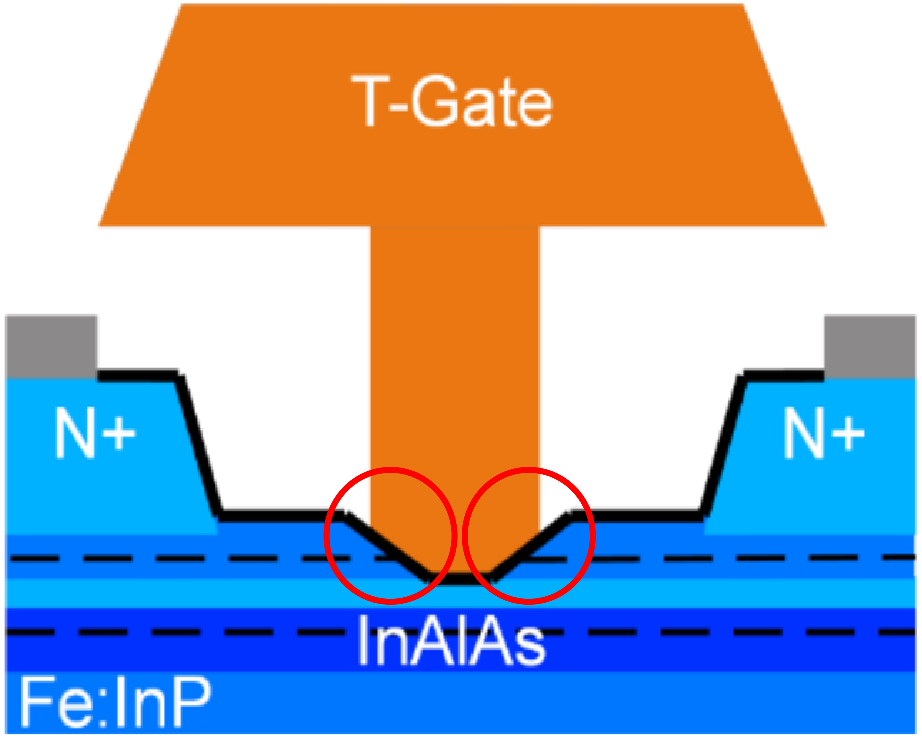
- Ft, fmax limited by CGS, CGD
- Fringe capacitance from gate-link overlap
  - T-gate filling
  - Gate alignment
- Extra capacitance from thick link
- <u>Need:</u>
  - <u>Self aligned process</u>
  - <u>Structure that's easier to fill</u>
  - <u>Thinner Link</u>



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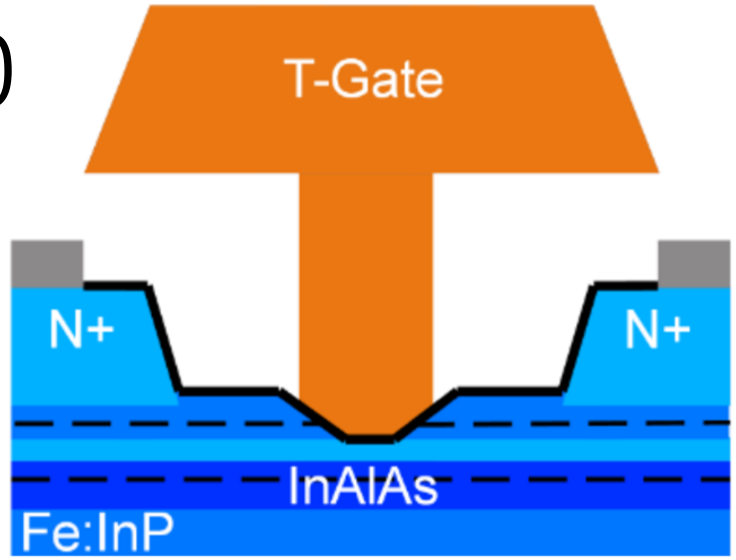
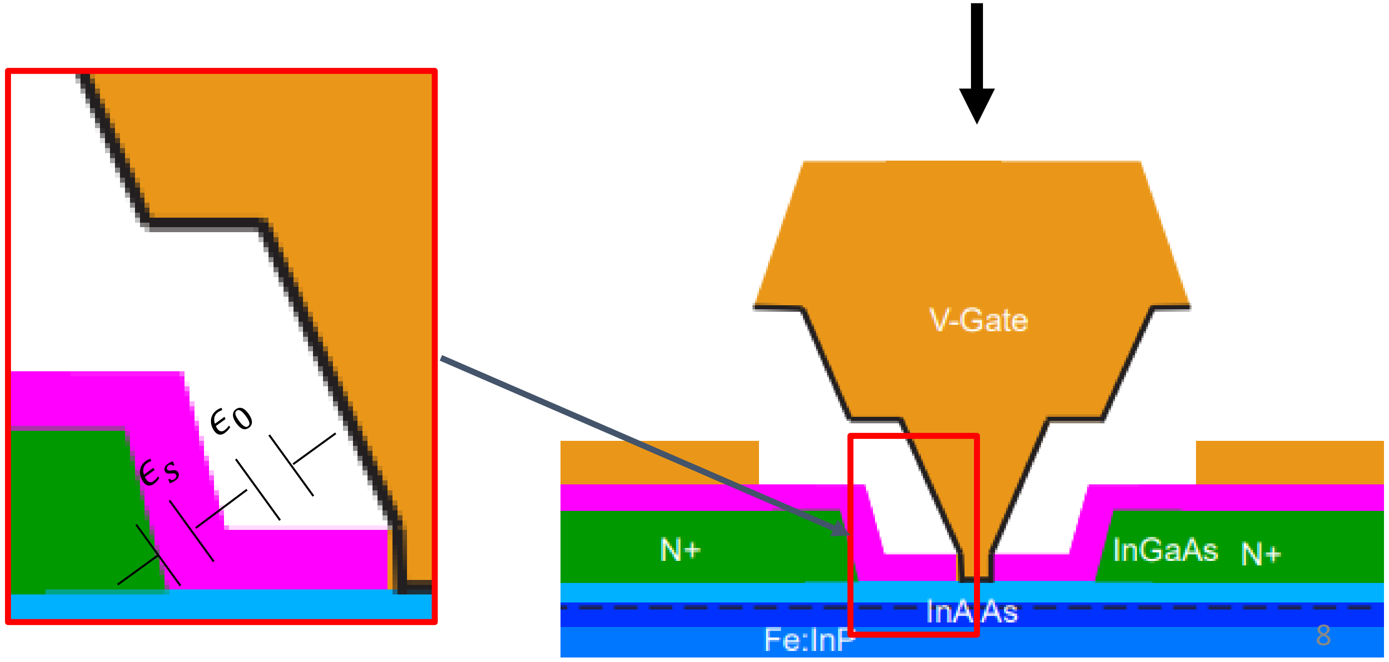
MOS-HEMTs 2.0

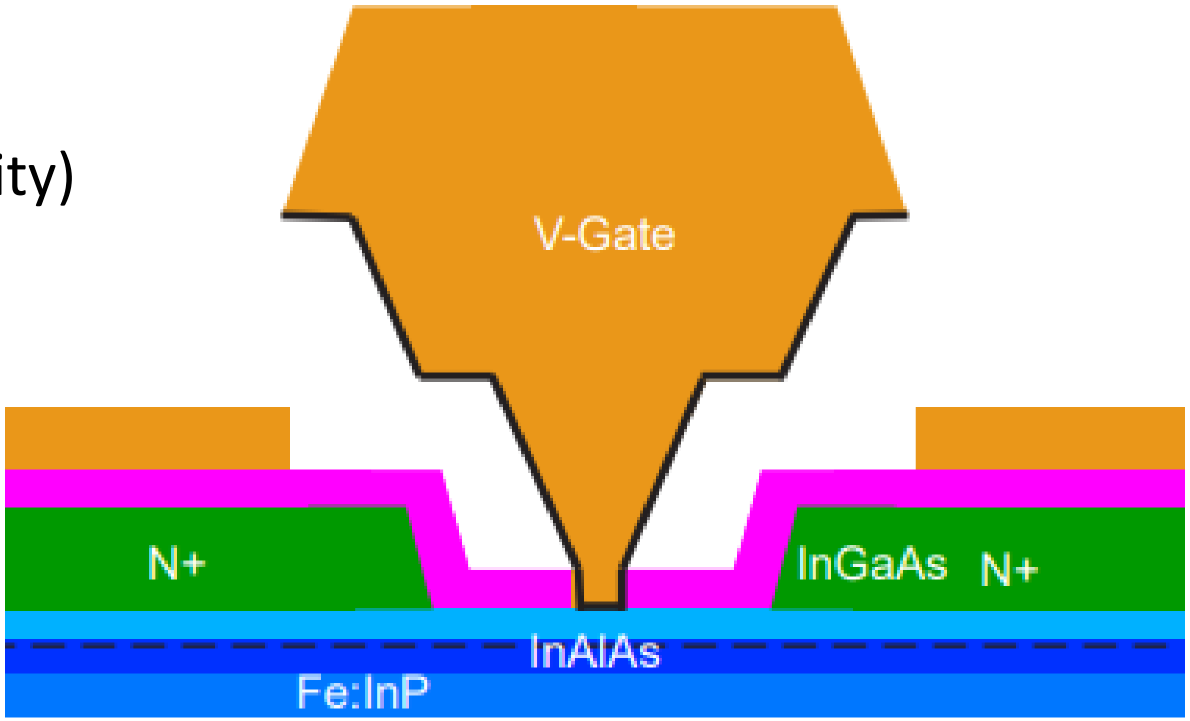
- Self aligned
  - Removes gate-link overlap
  - Reduces $C_{GS,f}$
- V-Gate
  - Easier to fill with metal
  - Better L_g scaling
- Thin link
  - More ϵ_0
  - Less ϵ_S
  - Reduces $C_{GS,f}$





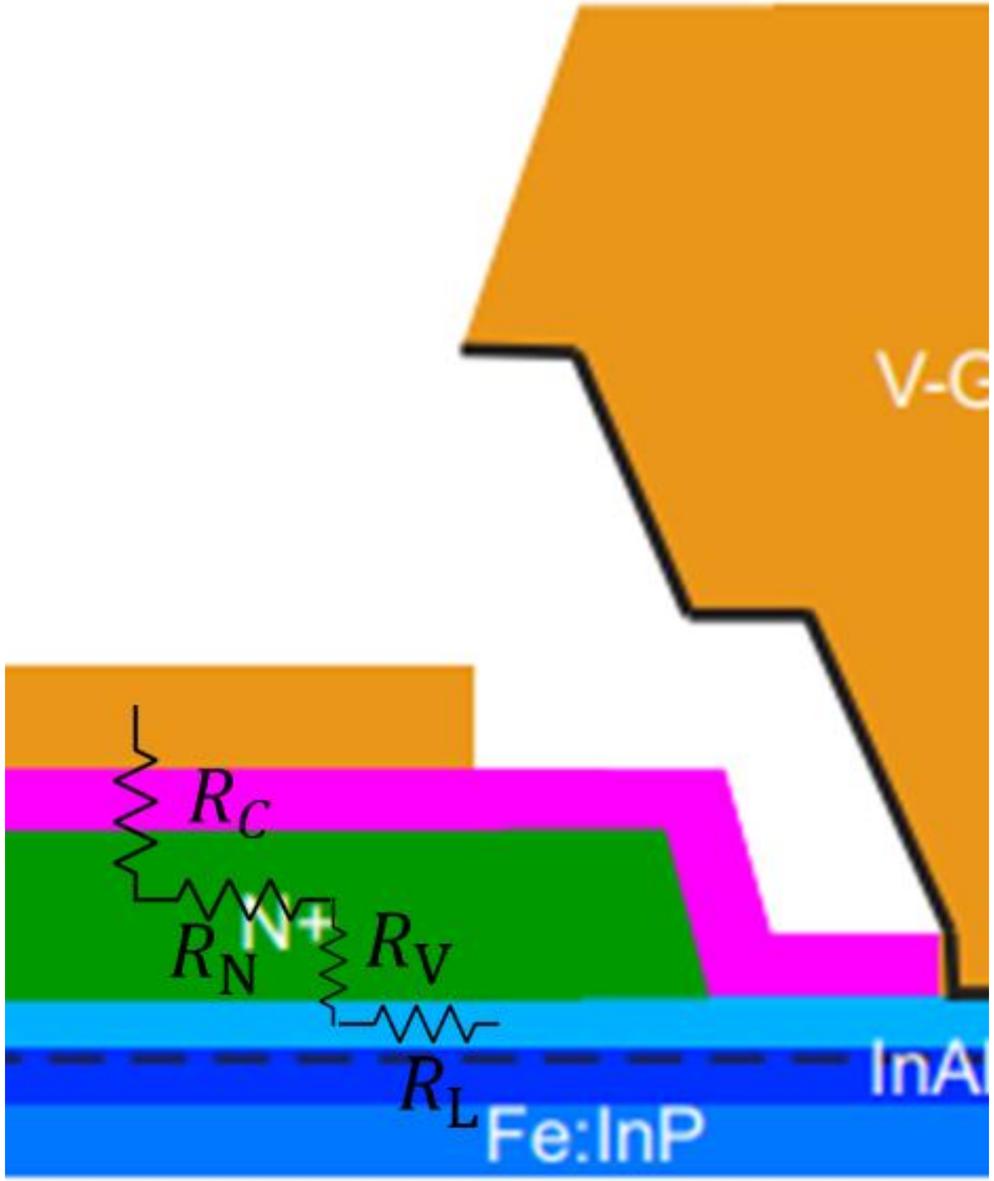
What is my variable?

1. Link thickness
   1. 3 nm minimum (source starvation)
   2. 20 nm maximum (maximized mobility)



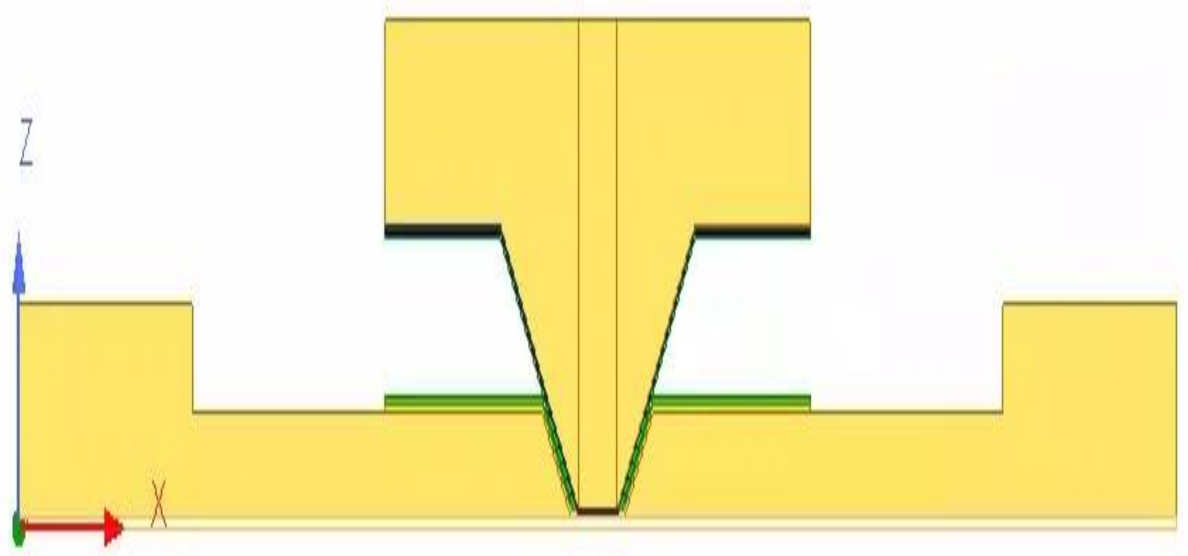
Rs breakdown

$$R_S = R_C + R_N + R_V + R_L$$
$$R_{Sheet} = (q * \mu_{Link} * n_{link})^{-1}$$
$$R_L = R_{sheet} * L_{sg}$$
$$t_{link} \downarrow \quad \rightarrow \quad \mu_{link} \downarrow$$



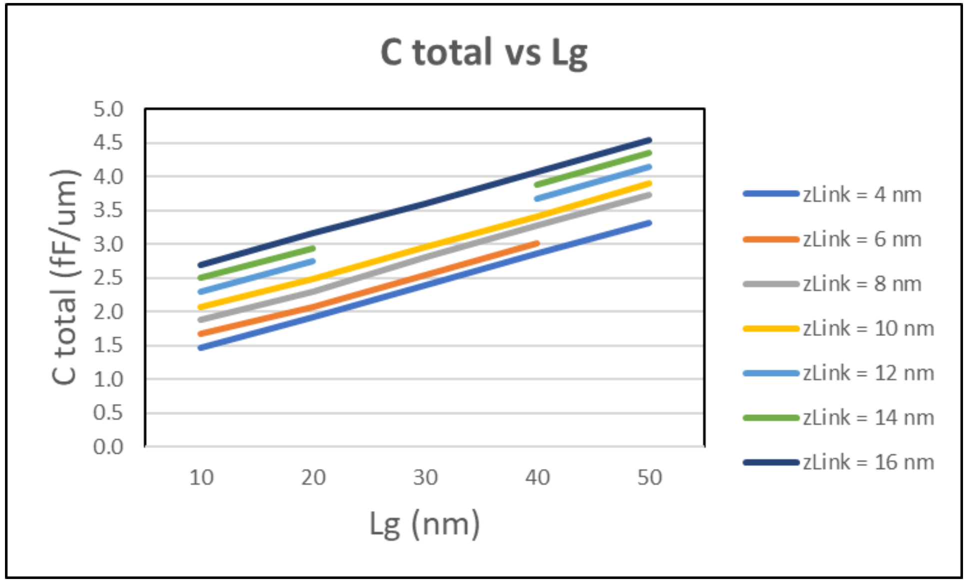
Capacitance

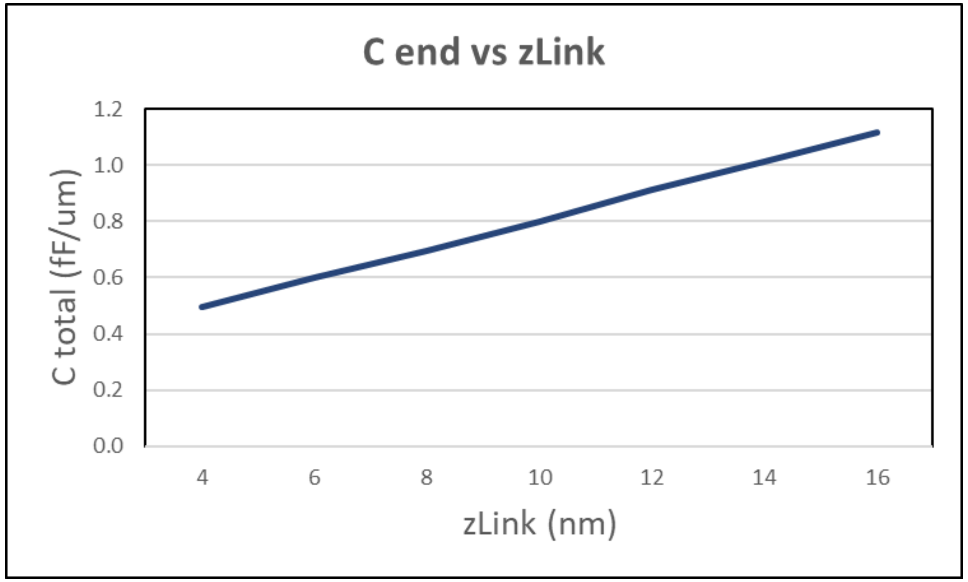
1. Create model in HFSS
2. Find capacitance of the model
3. Vary Lg
4. Find y intercepts
5. Divide by 2 to find CGS
6. Repeat with variations on the model



Cgs end vs Link Thickness

- Vary the thickness of the link
  - Assume channel is perfectly conducting (pessimistic)
  - Assume topside link doping is a perfect insulator (optimistic)
  - Results in a **STRONG** linear relationship between link thickness and end capacitance
- <u>Thinner (low mobility) links could be better?</u>





So What?

- *Ideal: Transit Time*

$$f_\tau \approx \frac{g_{m,e}}{2\pi(C_{gs}+C_{gd})}$$

$$\frac{1}{g_{m,e}} = \frac{1}{g_{m,i}} + R_S$$

$$\frac{1}{g_{m,e}} = \frac{1}{g_{m,i}} + R_C + R_N + R_L$$

So What?

- *Ideal: Transit Time*

$$\frac{1}{g_{m,e}} = \frac{1}{g_{m,i}} + R_S$$

$$\frac{1}{g_{m,e}} = \frac{1}{g_{m,i}} + R_C + R_N + R_L$$

$$f_\tau \approx \frac{g_{m,e}}{2\pi(C_{gs}+C_{gd})}$$

	traditional regrown link	"LEMT" link
link thickness (nm)	16.0	3.0
Rsheet (ohm/sq)	225.0	700.0
link distance (um)	0.05	0.05
Rlink (ohm*um)	11.3	35.0
Rs-Rlink (ohm*um)	65.0	65.0
Rs (ohm*um)	76.3	100.0
gmi (mS/um)	4.0	4.0
gme (mS/um)	3.07	2.86
change in gme		7%

So What?

- *Ideal: Transit Time*

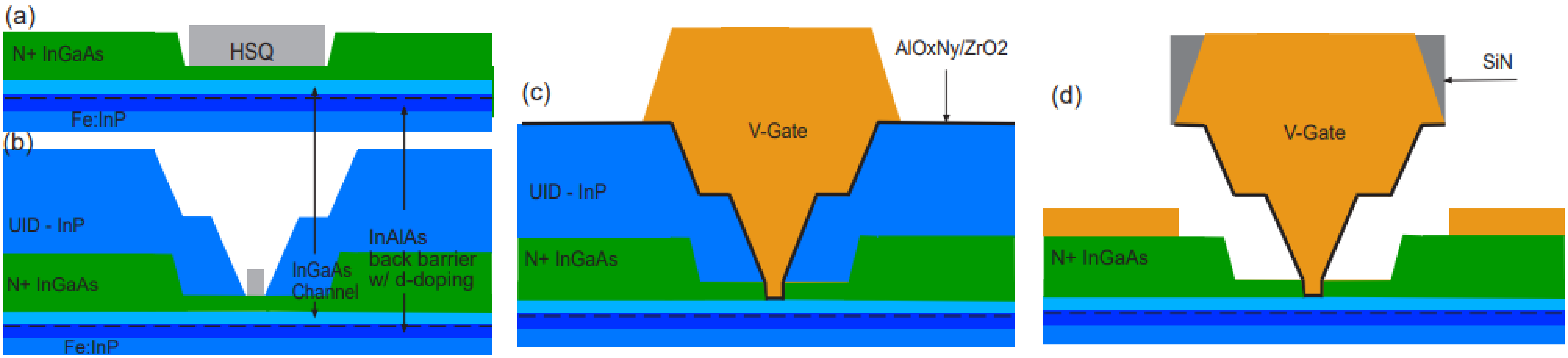
$$f_\tau \approx \frac{g_{m,e}}{2\pi(C_{gs}+C_{gd})}$$

$$\frac{1}{g_{m,e}} = \frac{1}{g_{m,i}} + R_S$$

$$\frac{1}{g_{m,e}} = \frac{1}{g_{m,i}} + R_C + R_N + R_L$$

	traditional regrown link	"LEMT" link
link thickness (nm)	16.0	3.0
Cch (fF/um)	0.3	0.3
CGD (fF/um)	0.3	0.3
CGS end (fF/um)	1.1	0.4
CGS + CGD (fF/um)	1.7	1.0
change in capacitance		41%

Process Flow



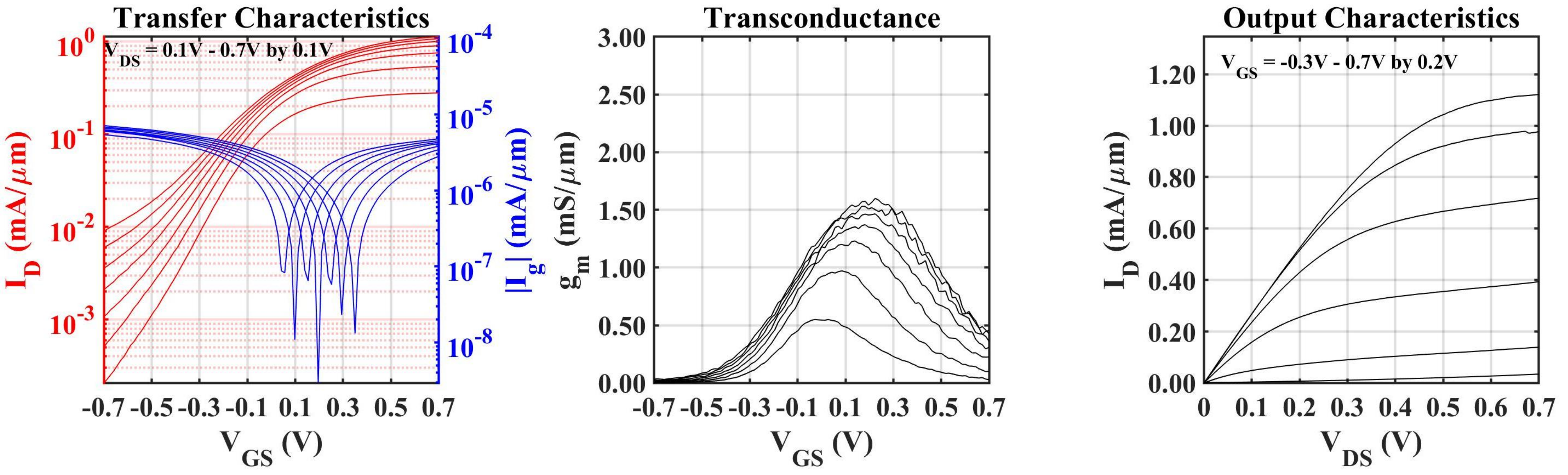
a) Epi + Regrowth 1

b) Regrowth 2

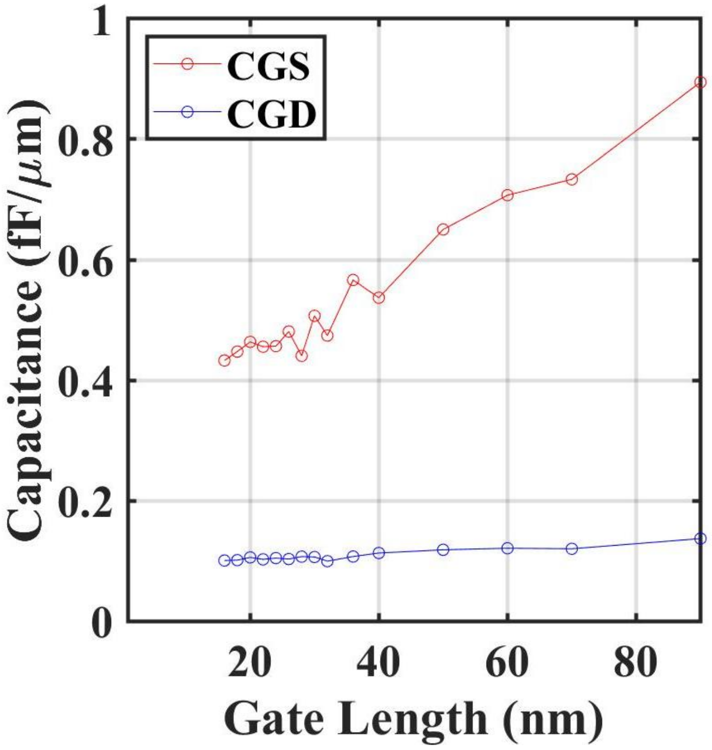
c) Digital etch, high-k, and gate metal

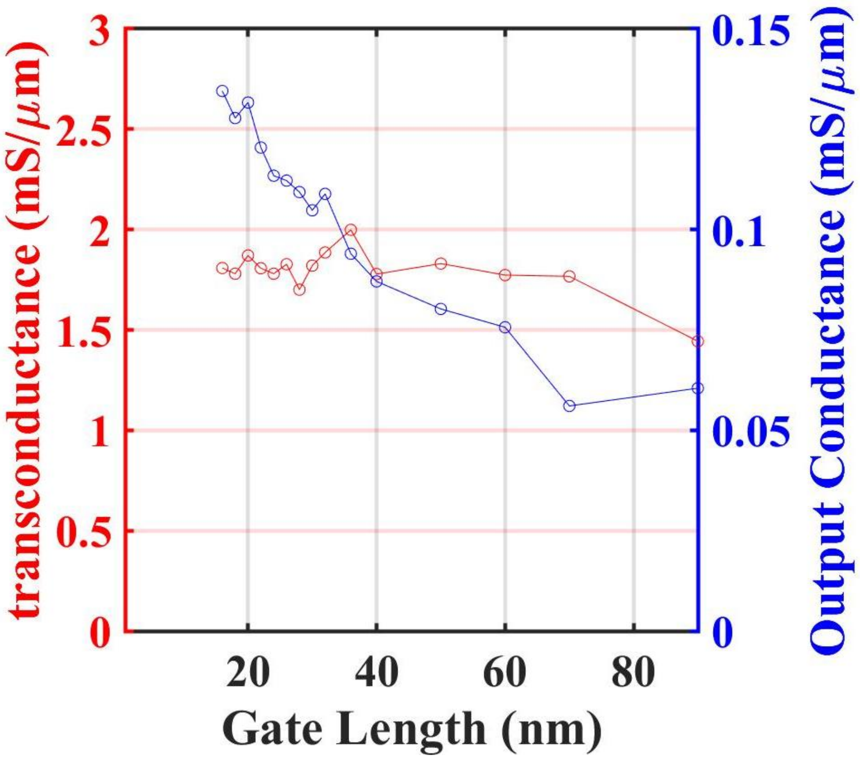
d) high-k etch, sidewall, sacrificial etch, mesa isolation, and contacts

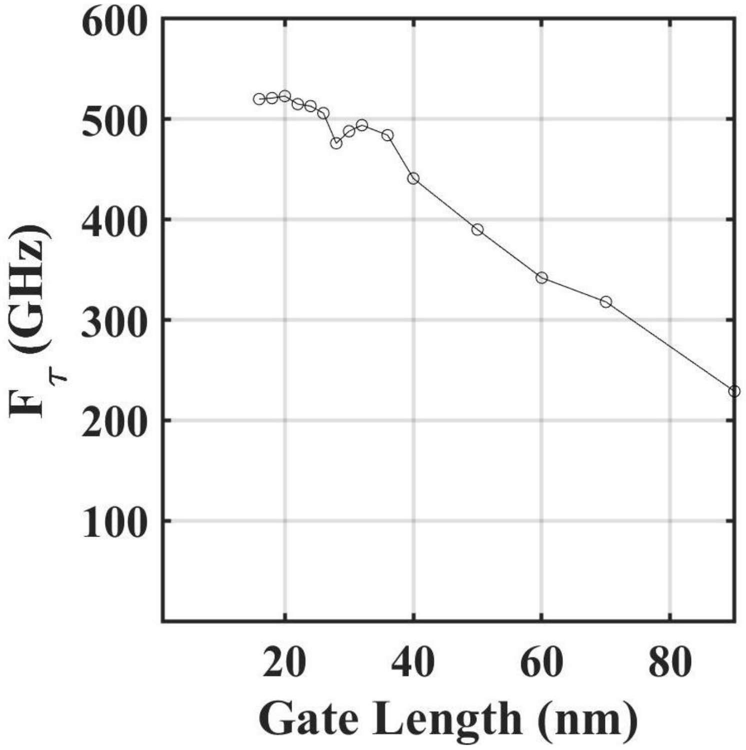
DC results – Lg = 22 nm



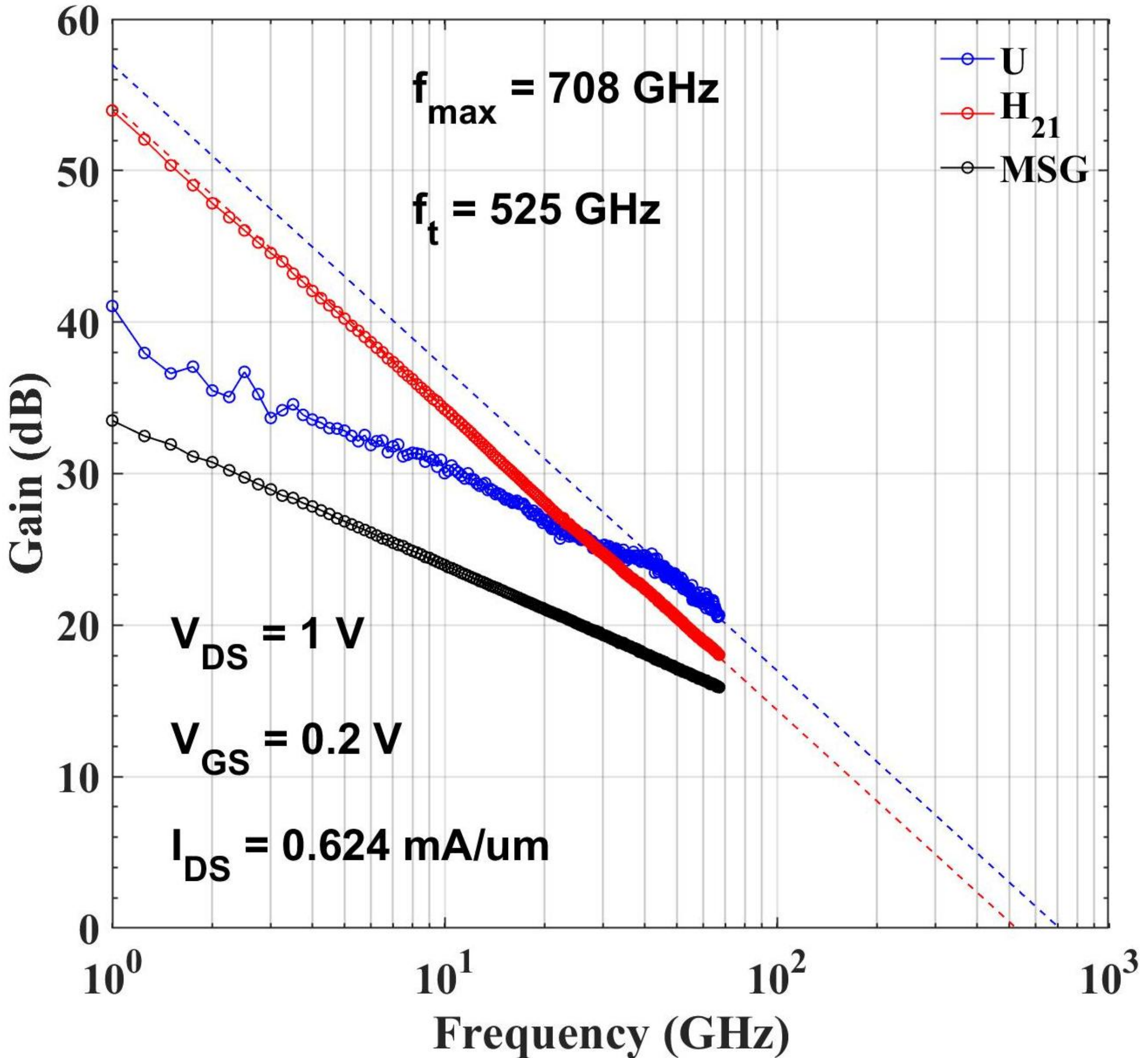
RF results vs Gate Length

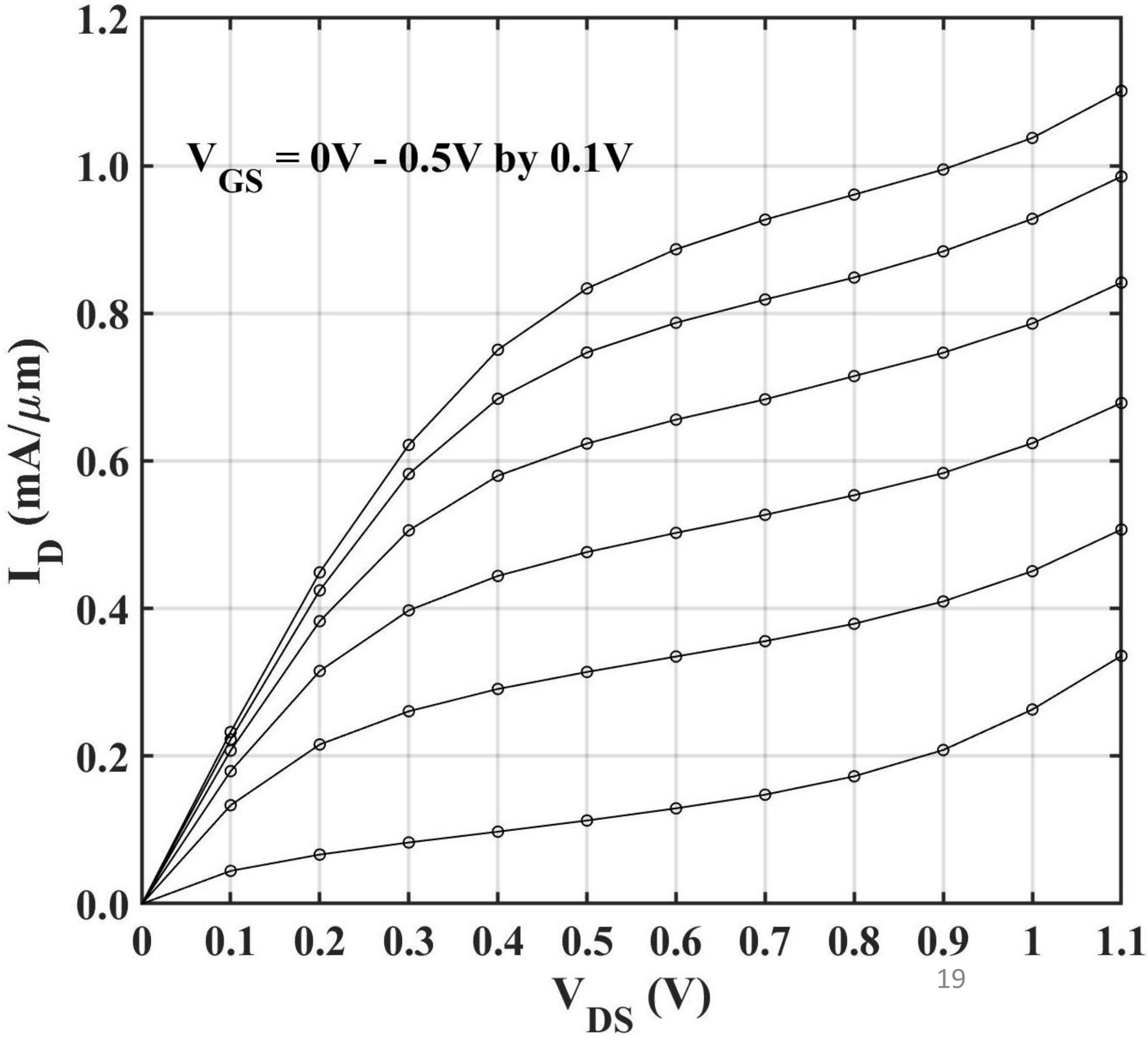




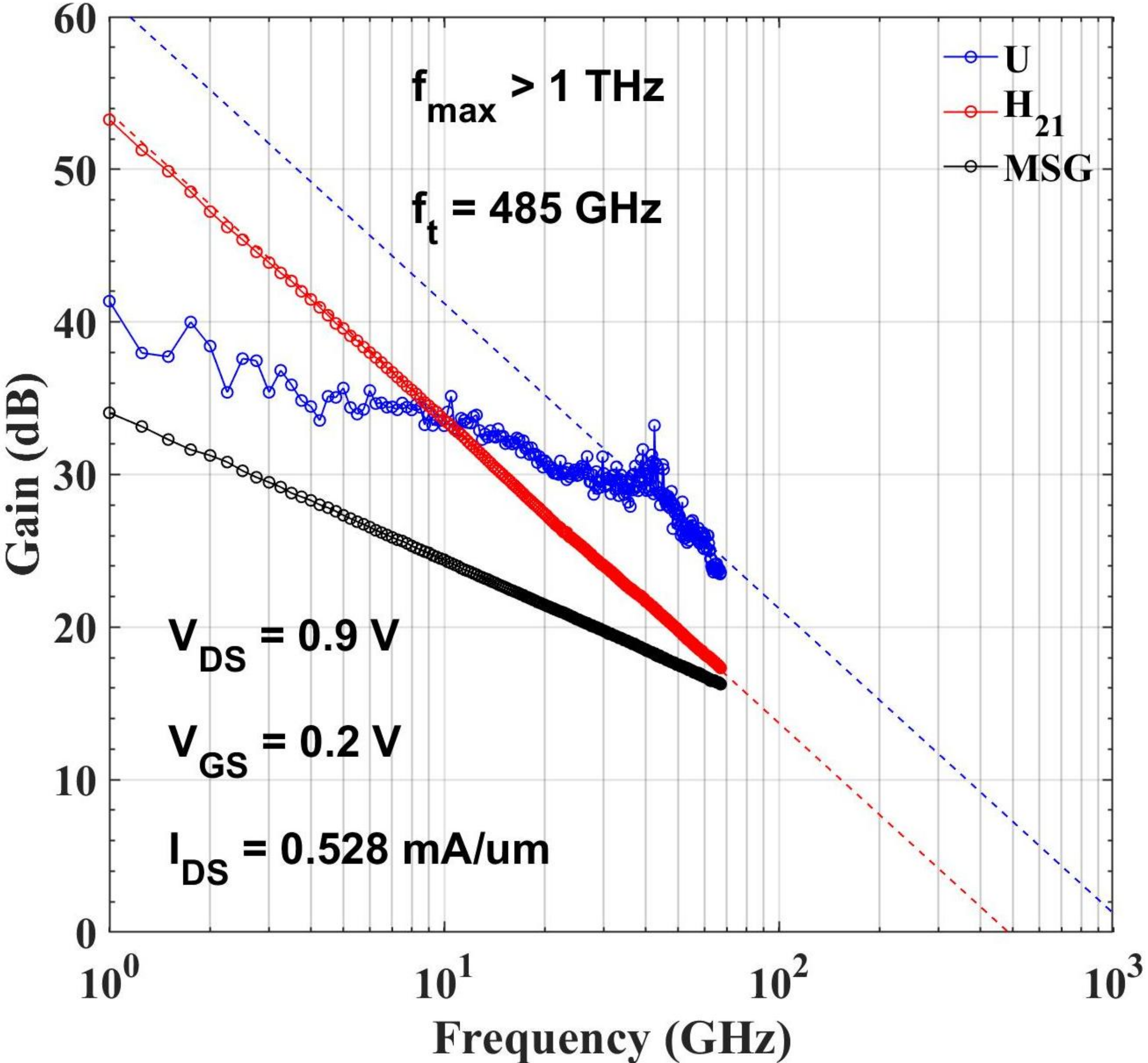


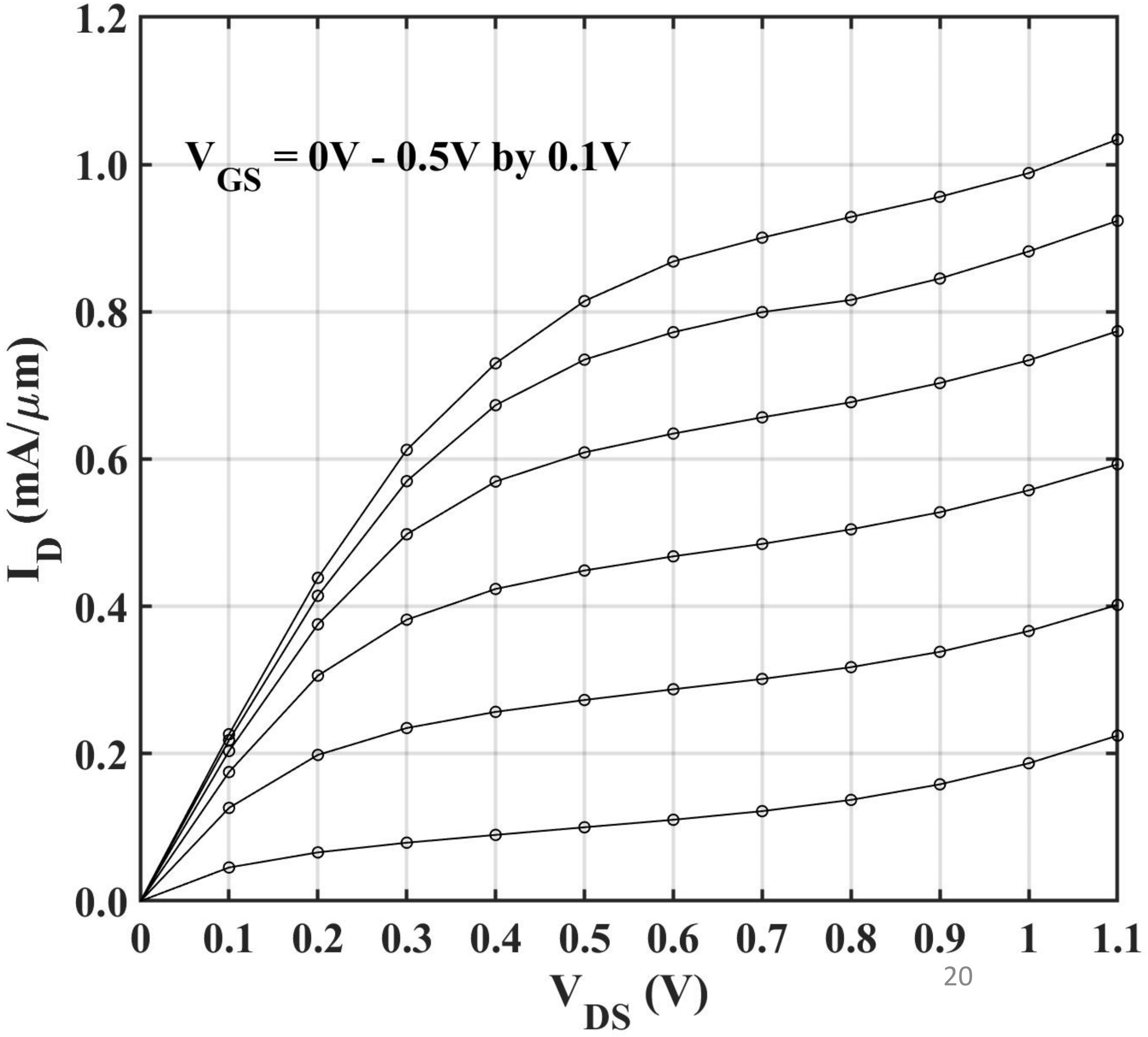
Mixed Results – Lg = 20 nm



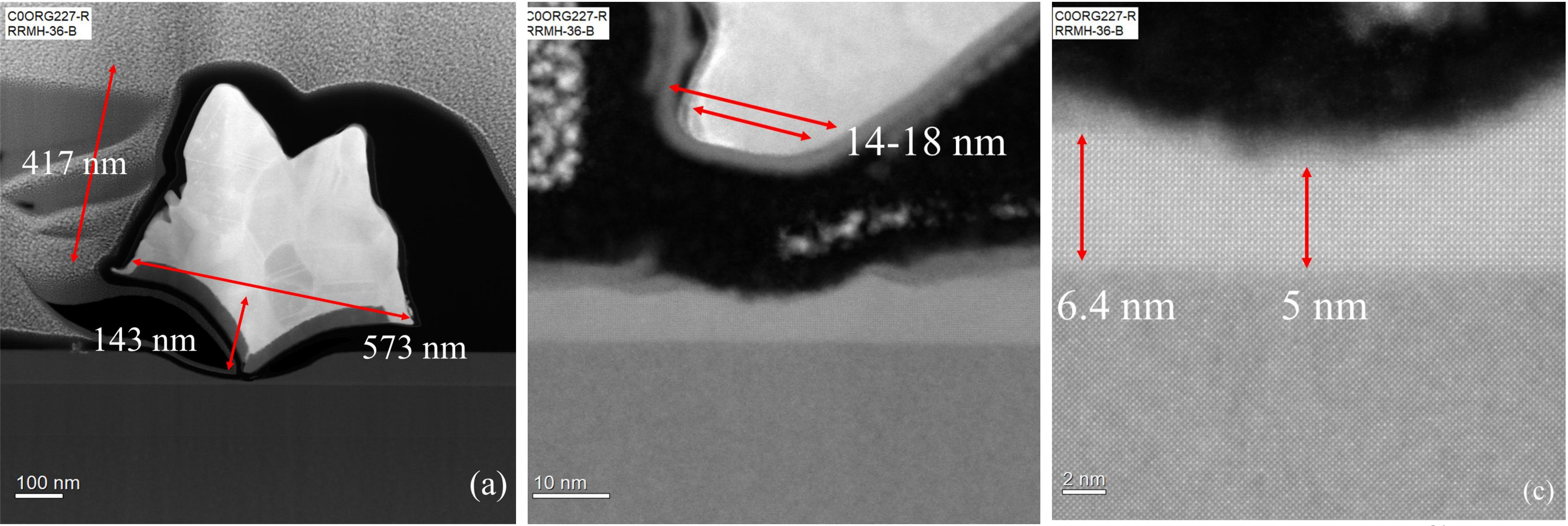


Mixed Results – Lg = 36 nm





TEM – Lg = 18 nm


C0ORG227-R
RRMH-36-B
417 nm
143 nm
573 nm
100 nm
(a)
C0ORG227-R
RRMH-36-B
14-18 nm
10 nm
C0ORG227-R
RRMH-36-B
6.4 nm
5 nm
2 nm
(c)

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References

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