UNIVERSITY OF DELAWARE
ENGINEERING

GaN Metal Insulator Semiconductor High Electron Mobility Transistors using TiAlO and HfZrO as the gate dielectric

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ELECTRICAL & COMPUTER ENGINEERING

Introduction

Table 1 Key characteristic parameters of typical semiconductor materials

Material	Si	GaAs	InP	GaN
Band gap *Eg* (eV)	1.12	1.42	1.35	**3.45**
Electron mobility μ_e [cm^2/(V•s)]	1400	8500	5400	**2000**
Saturation electron velocity v_{sat} (10^7cm/s)	1	2	2.7	**2.7**
Breakdown voltage *Ec* (MV/cm)	0.3	0.4	0.5	**3.3**
Thermal conductivity κ [W/(cm•K)]	1.5	0.5	0.69	**2**

GaN material characteristics：

- ✓ **Large band gap;**
- ✓ **High Saturation electron velocity**
- ✓ **High breakdown electric field;**
- ✓ **High thermal conductivity;**

High frequency and high power applications.

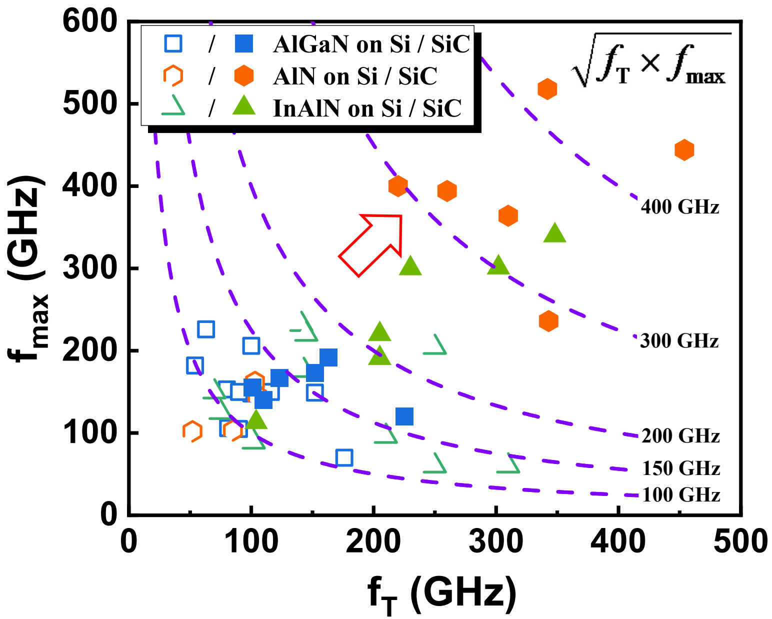
InP material characteristics:

- ✓ **High Saturation electron velocity**

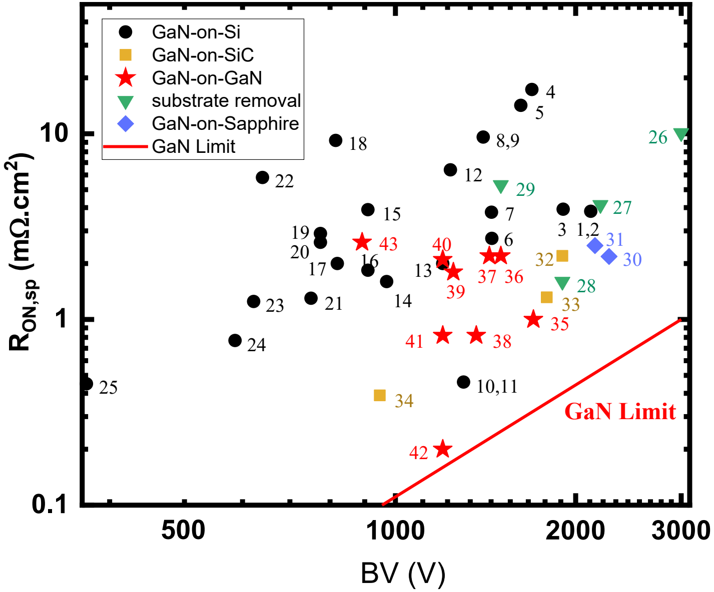
High frequency applications

Introduction

Speed



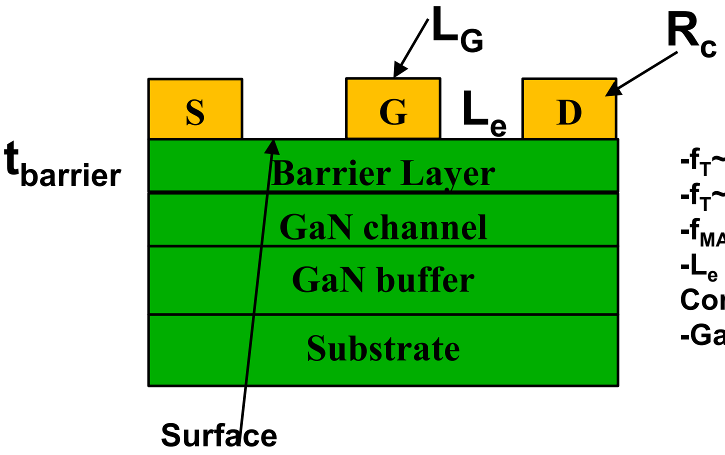
Power



State-of-the-art GaN HEMT power and speed

Both RF and DC performance needs to be improved

Factors of RF performance GaN HEMTs



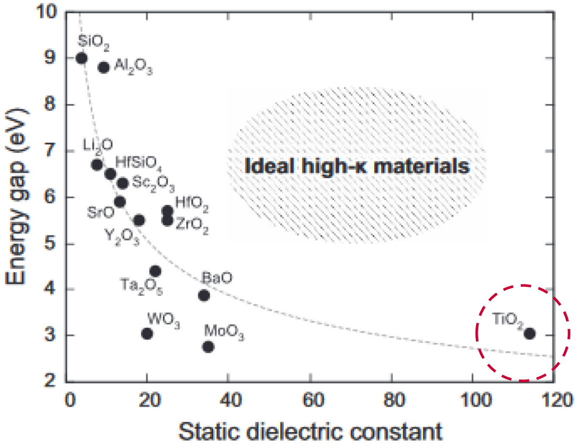
-f_T~$t_{barrier}$ needs to be optimized
-f_T~L_G needs to be reduced
-f_{MAX}~ R_g needs to be maximized
-L_e needs to be minimized for reduced parasitic resistance
Contact resistance R_c
-Gate leakage current should be reduced

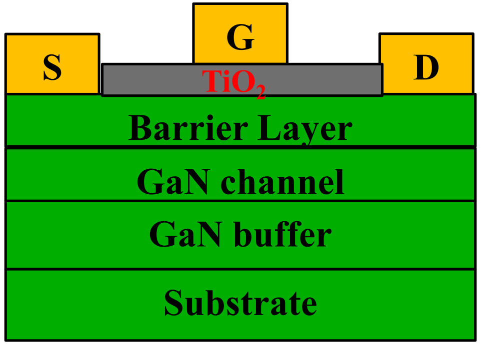
-AlGaN, InAlN can be the barrier layer, InAlN is better due to the better scaling behavior

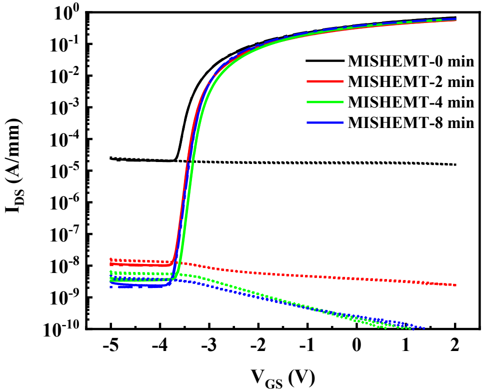
For enhanced RF, thinner barrier is needed; however, when $t_{barrier}$ reduces, gate leakage increases, leading to degraded breakdown performance; an oxide is needed in between gate and channel.

Recap from last year's results

-In the previous workshop, I introduced TiO_2 as the dielectric



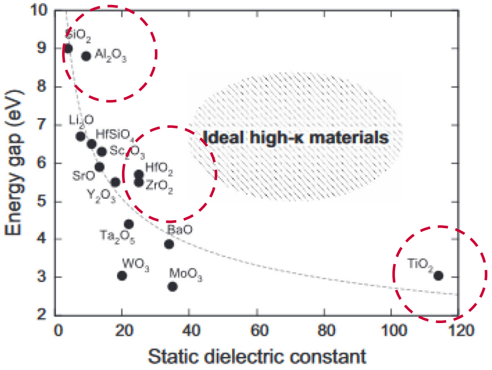


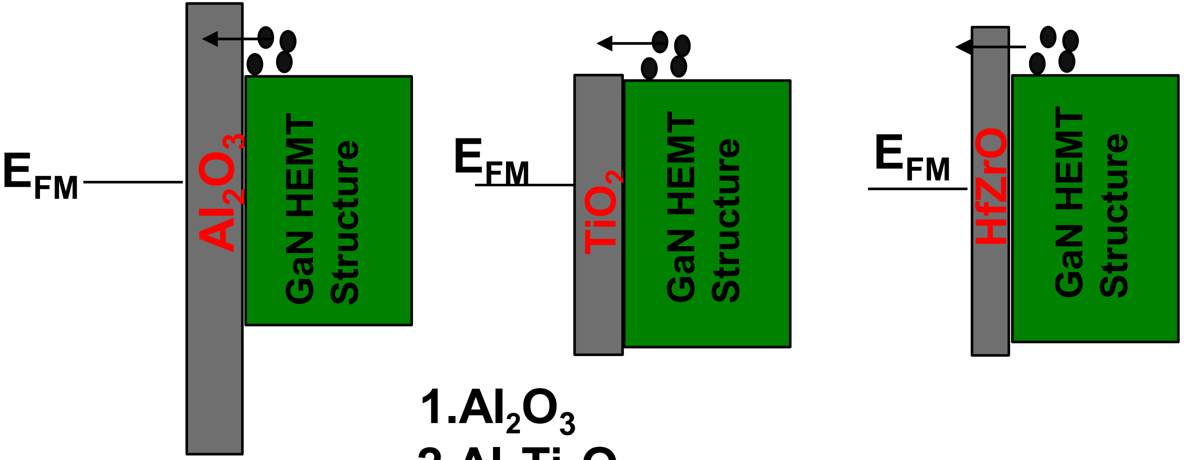


TiO_2 N_2O treatment is needed; Longer treatment will lead to crystallization of TiO_2 as well as the oxidation of channel, thus we need new oxide materials.

Experimental Design

-Revisit the graph



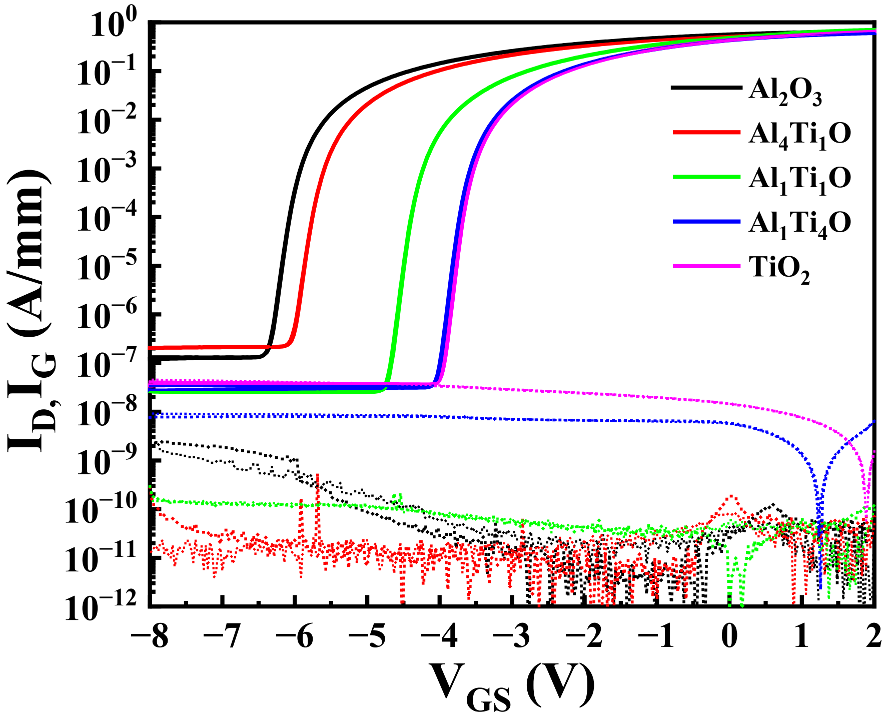


1. Al_2O_3
2. Al_1Ti_4O
3. Al_1Ti_1O
4. Al_4Ti_1O
5. TiO_2
6. HfZrO

	Bandgap	Dielectric constant
TiO_2	~3.4eV	80~120
Al_2O_3	~9eV	~9

Both high k and high bandgap material is needed; Al_2O_3 had high bandgap dielectric constant; while TiO_2 has low bandgap and high dielectric constant

Results

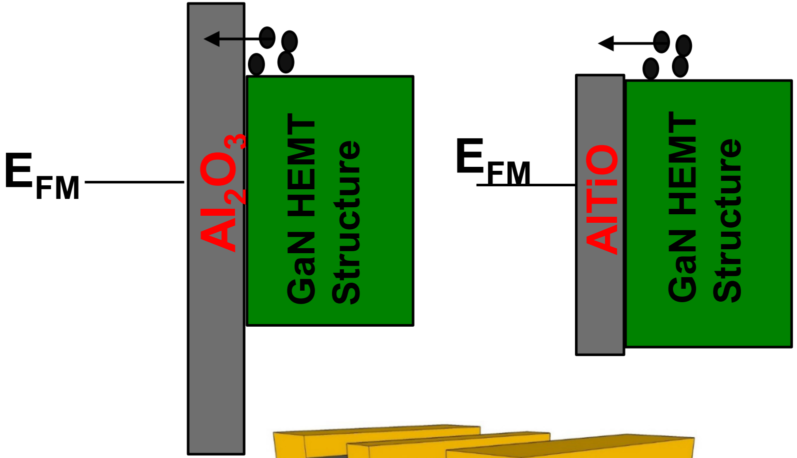


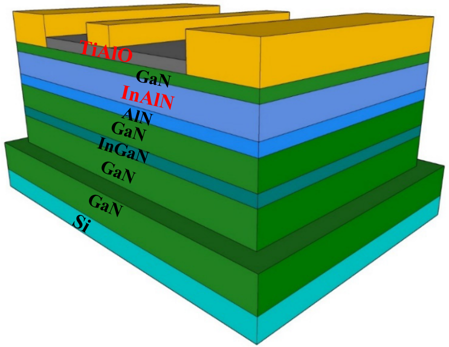
Oxide	*SS* (mV/dec)	On off Ratio	n_{2DEG} (cm^{-2})	Avg. *k*	ε_r	D_{it} ($eV^{-1}cm^{-2}$)
Al_2O_3	100	5.4×10^6	1.22×10^{13}	1.62	13.06	7.04×10^{12}
Al_4Ti_1O	114	3.1×10^6	1.20×10^{13}	1.77	14.38	7.32×10^{12}
Al_1Ti_1O	84	2.6×10^7	1.14×10^{13}	1.94	32.27	4.27×10^{12}
Al_1T_4O	98	2.1×10^7	9.58×10^{12}	2.20	29.55	6.06×10^{12}
TiO_2	85	1.9×10^7	1.02×10^{13}	2.53	45.82	3.03×10^{13}

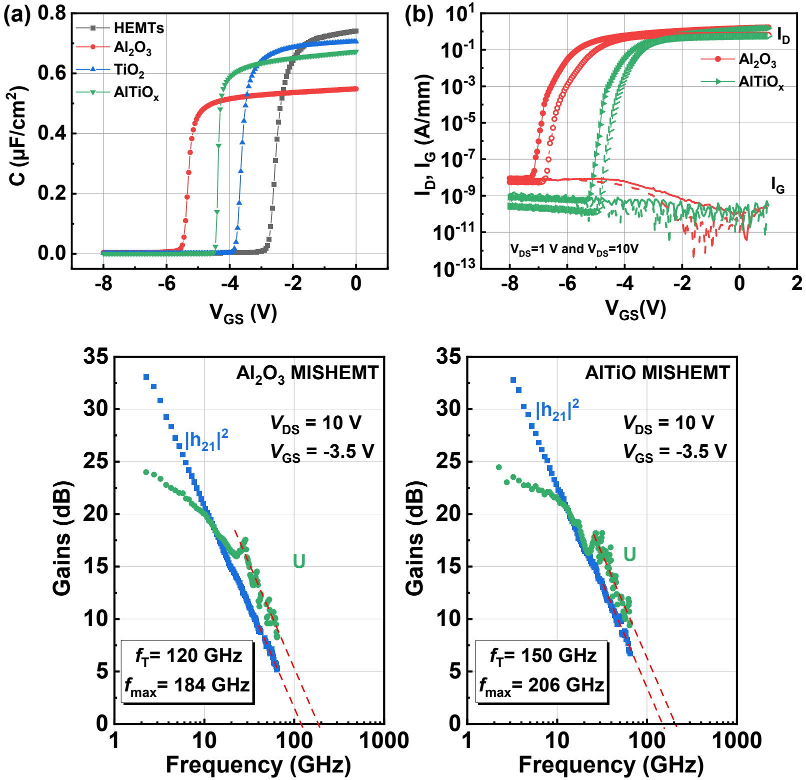
The more Al content, the less gate leakage

TiAlO

15nm thick gate dielectric



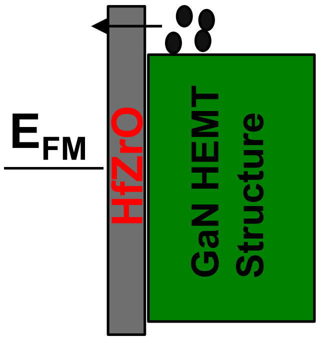


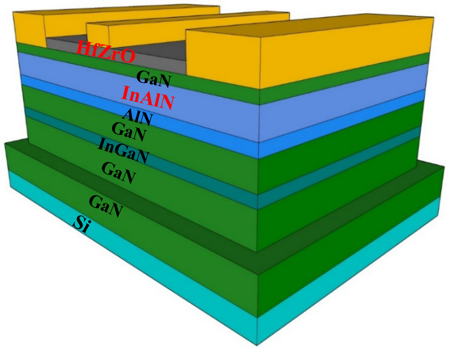


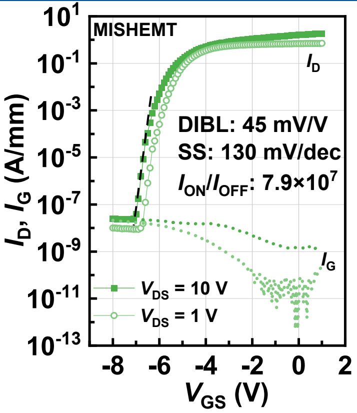
Submitted

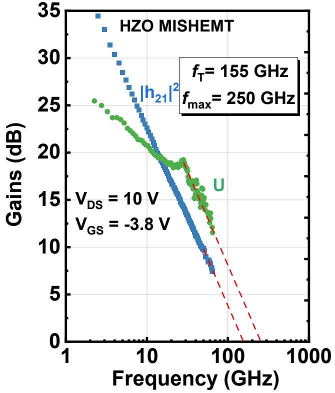
Results

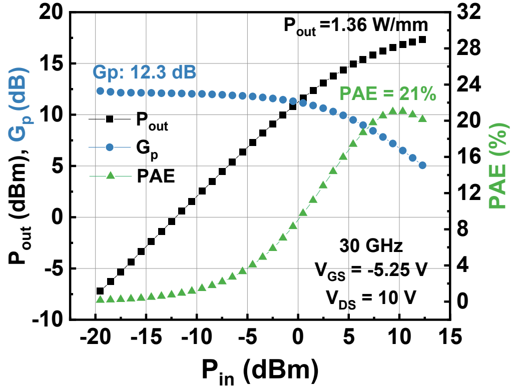
2nm thick HfZrO gate dielectric

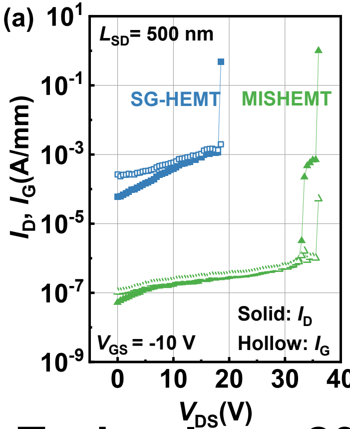


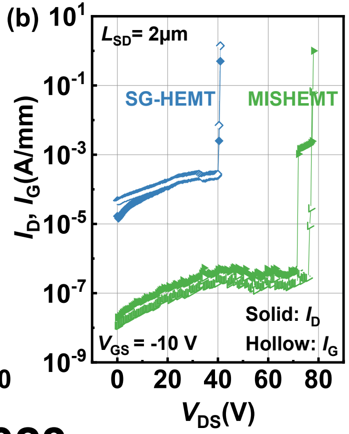








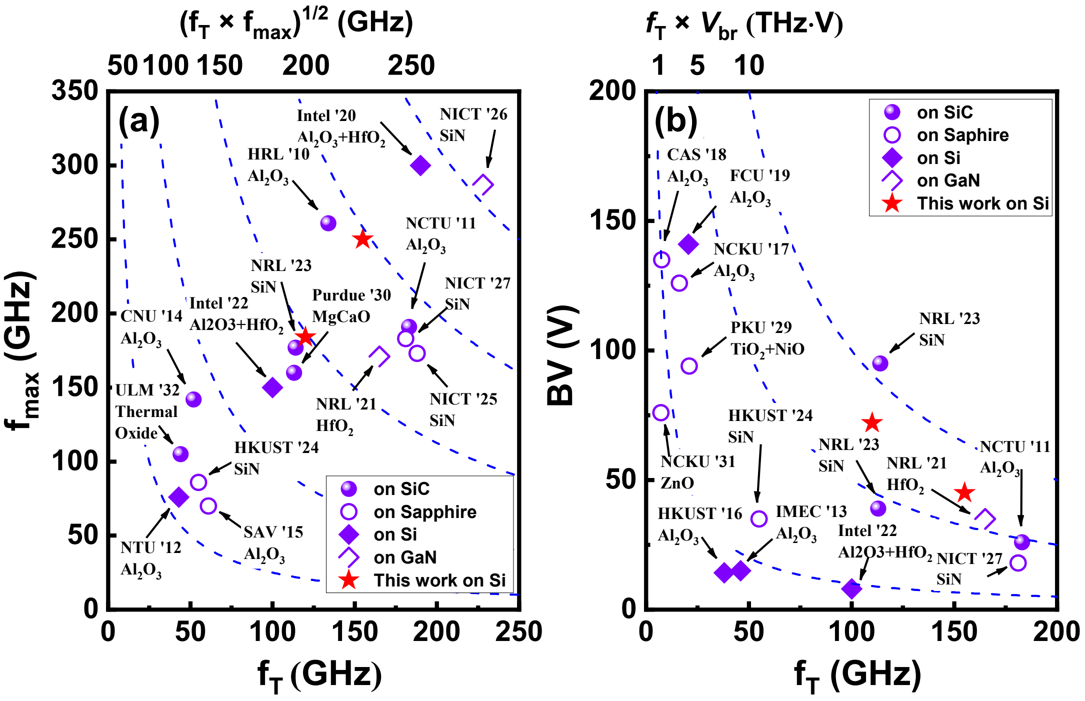




Measured from AFRL (by Kelson Chabak's group)

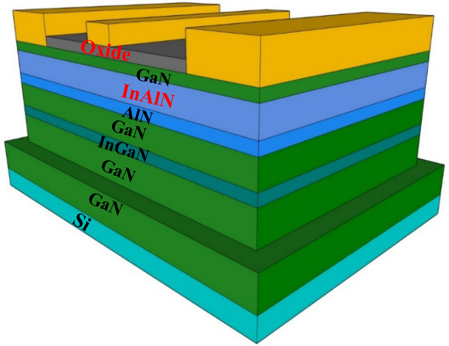
Semiconductor Science Technology, 2023

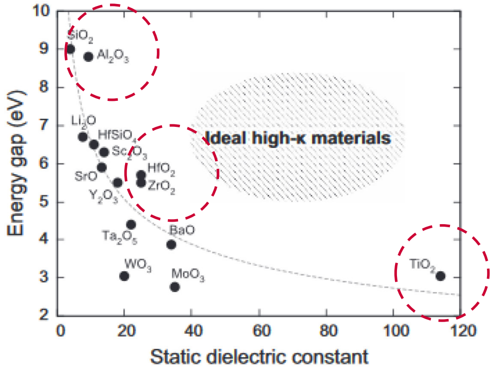
Comparison with other MISHEMTs

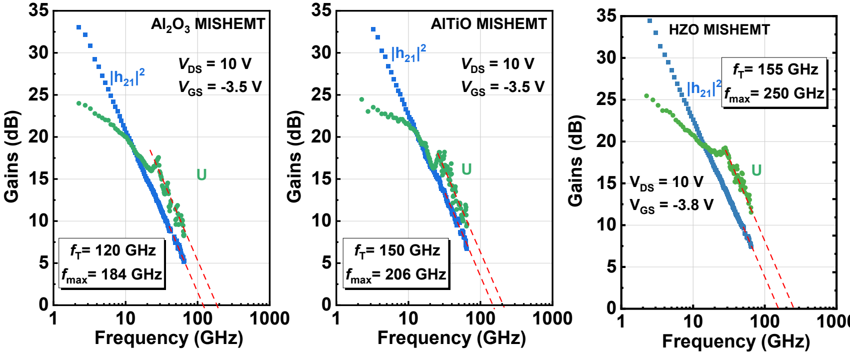


Conclusions

- GaN MISHEMTs with Ti_1Al_1O exhibits best DC and RF performance
- GaN MISHEMTs with 2nm HfZrO exhibits excellent DC and RF performance
- In future, we may scale down TiAlO further







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