

Study of Interface Charges Between In-situ Grown Dielectric and GaN/AlGaN HFET Structure by Metal-organic Chemical Vapor Deposition

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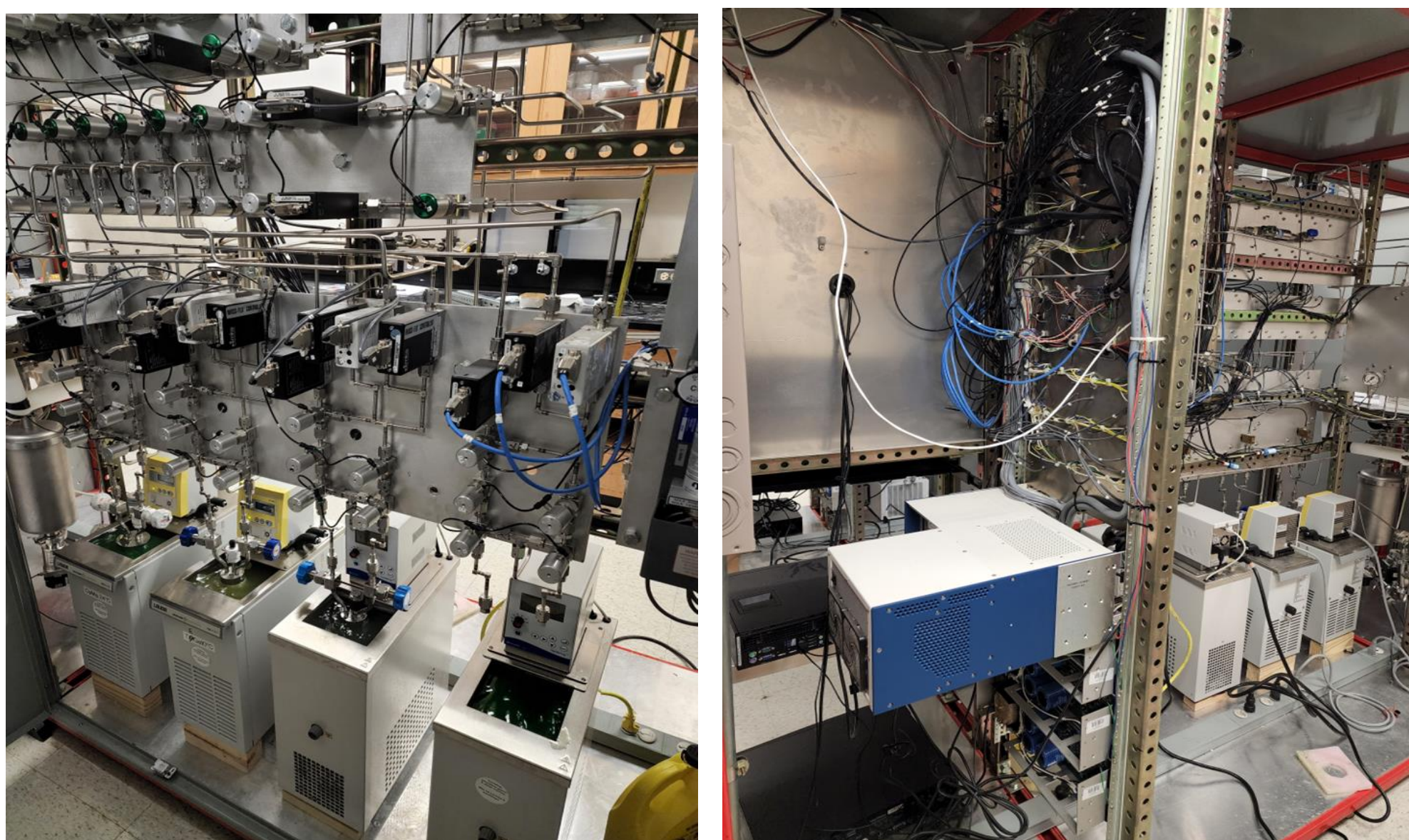
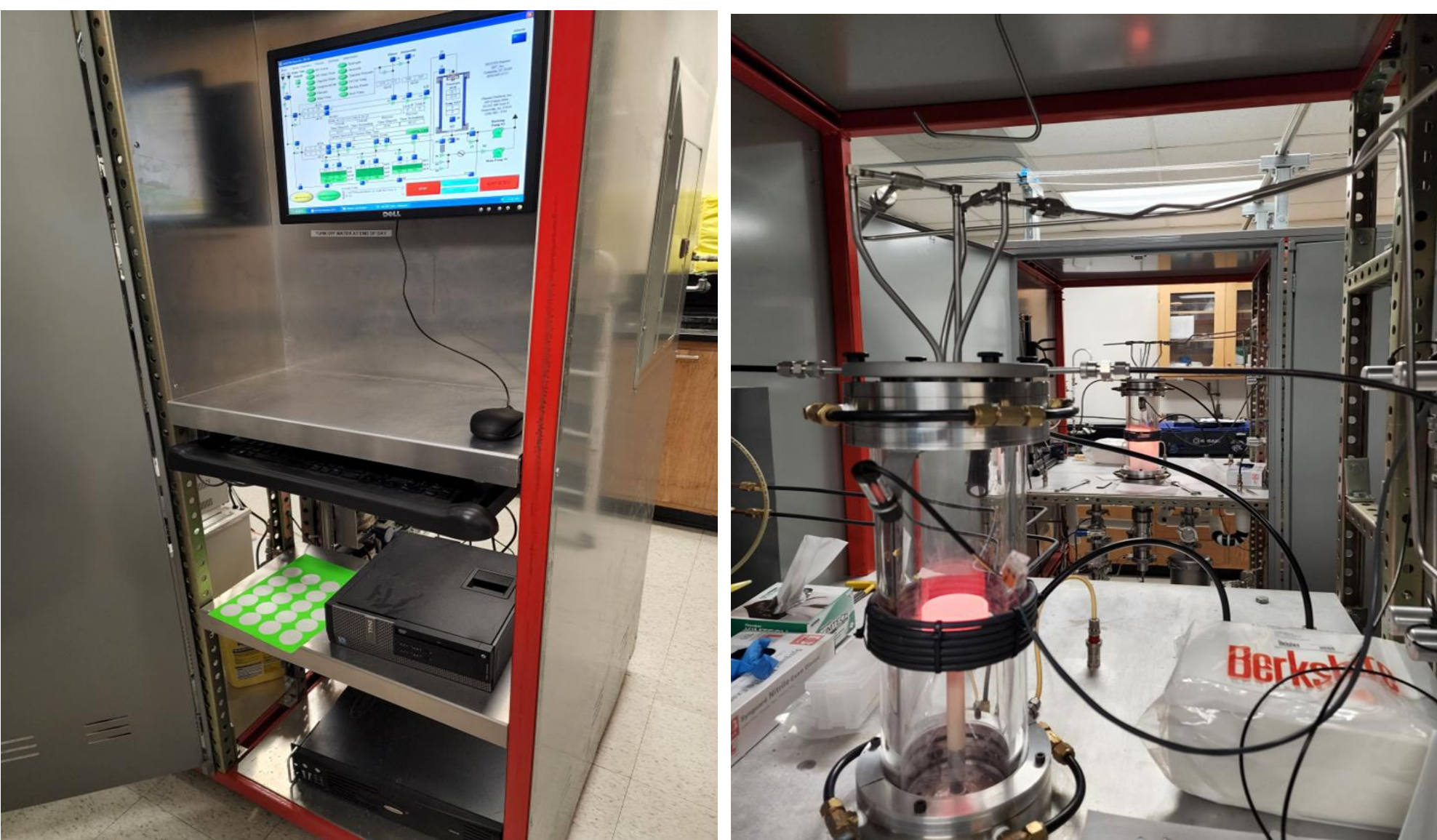
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Introduction

- The oxide layer in MOSHFET structure reduces the gate leakage current and allows large gate voltage swing.
- In this presentation we will show the results of GaN/AlGaN heterostructure field effect transistor (HFET) structure capped with a dielectric layer in a single reactor without breaking the vacuum, called in-situ process
- We will show the results of HFET capped with Ga_2O_3 where the structure grown by in-situ exhibited density of interface charges $4 \times 10^{12} \text{ cm}^{-2}$ whereas the same structure grown by ex-situ process shows the density of interface charges up to $1 \times 10^{13} \text{ cm}^{-2} \text{ eV}^{-1}$.

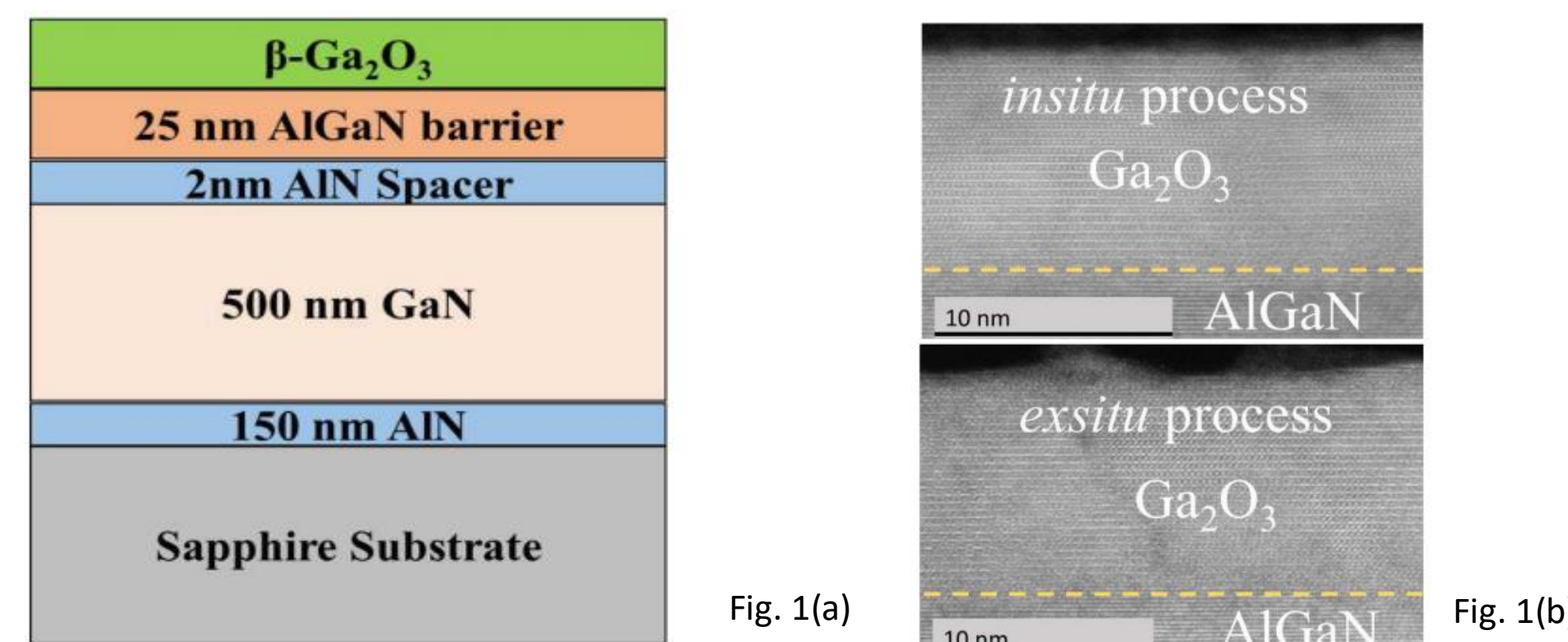
Growth by MOCVD System

- Gallium oxide (Ga_2O_3) with a dielectric constant of 10.6 and bandgap of 4.9 eV, by metal-organic chemical vapor deposition (MOCVD) on an AlGaN/GaN-based HFET structure to create a complete in-situ MOSHFET structure in a single process step, starting from the sapphire substrate and without breaking vacuum.



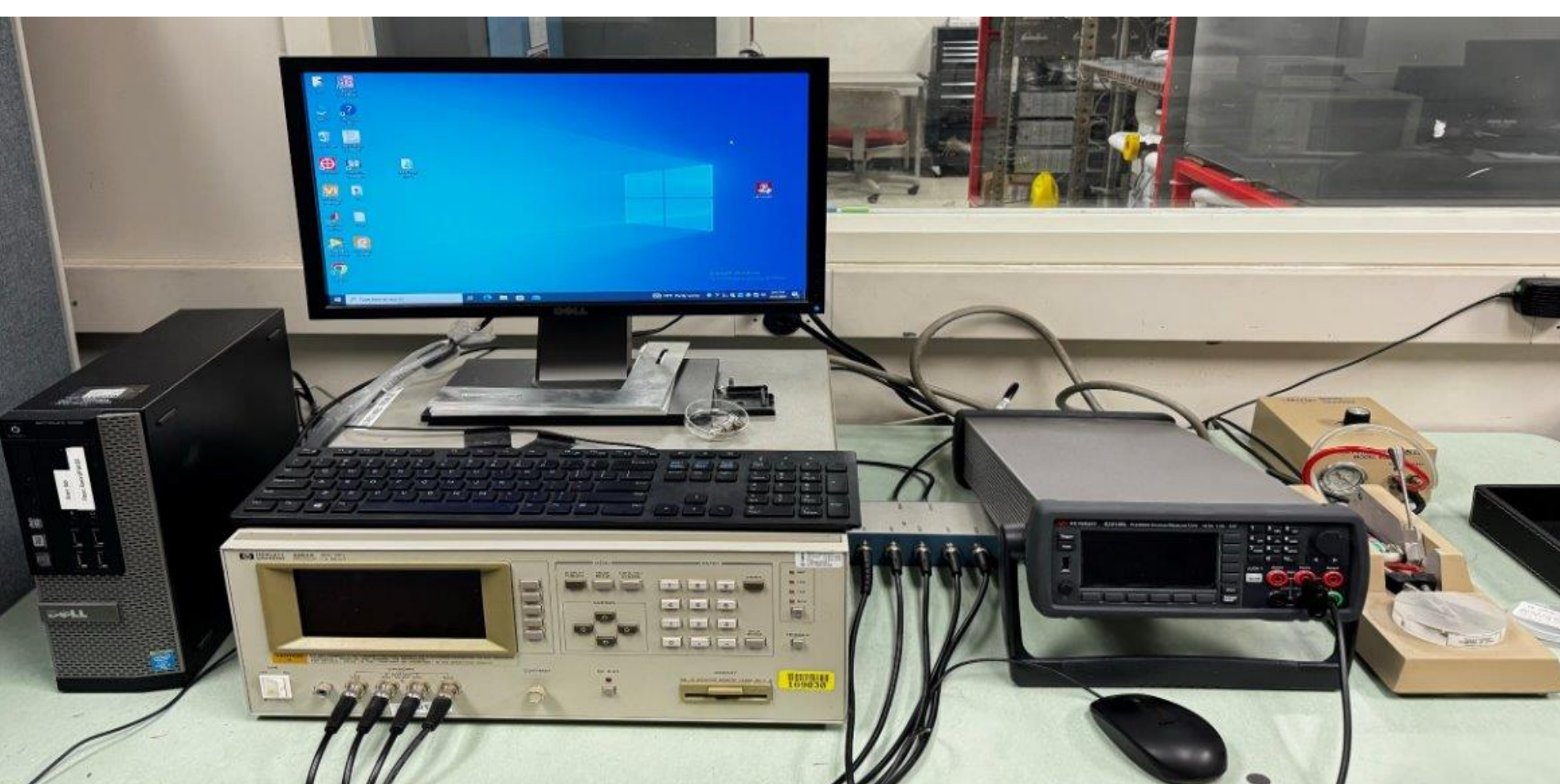
- For comparison, we created an ex-situ MOSHFET structure where the Ga_2O_3 layers were grown on the HFET structure exposure to air.
- The epilayer structures for this study were deposited on a c-plane sapphire substrate. Trimethylaluminum (TMAI), triethylgallium (TEGa), ammonia (NH_3), and ultra-high purity oxygen (O_2) were used as aluminum (Al), nitrogen, and oxygen precursors.
- For the in-situ growth process the system was nitrogen purged for 30 min prior to growing Ga_2O_3 in order to avoid an overlap of oxygen and hydrogen species at 50 Torr.

Schematic of HEMT Structure



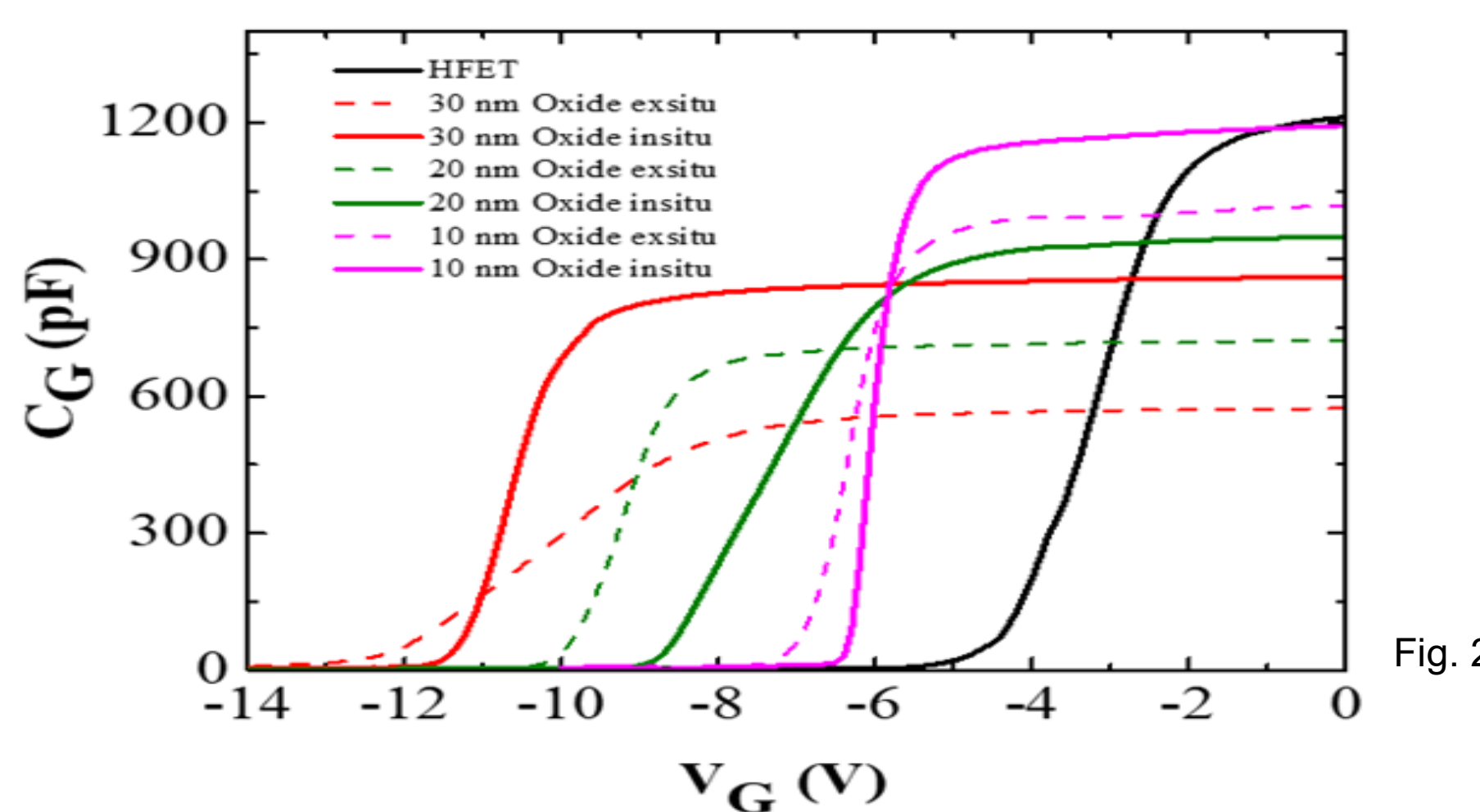
- Figure 1(a) exhibits the schematic of the MOSHFET structure. Figures 1(b) shows the high-resolution transmission electron microscopy (HR-TEM) images of the barrier AlGaN and Ga_2O_3 interface for a 10 nm thick Ga_2O_3 MOSHFET structure with oxide layer grown by in-situ and ex-situ processes.
- We observe no apparent defects or imperfections, such as dislocations, stacking faults, or grain boundaries, present at the interface in both in-situ and ex-situ processes.

CV Characterization Technique



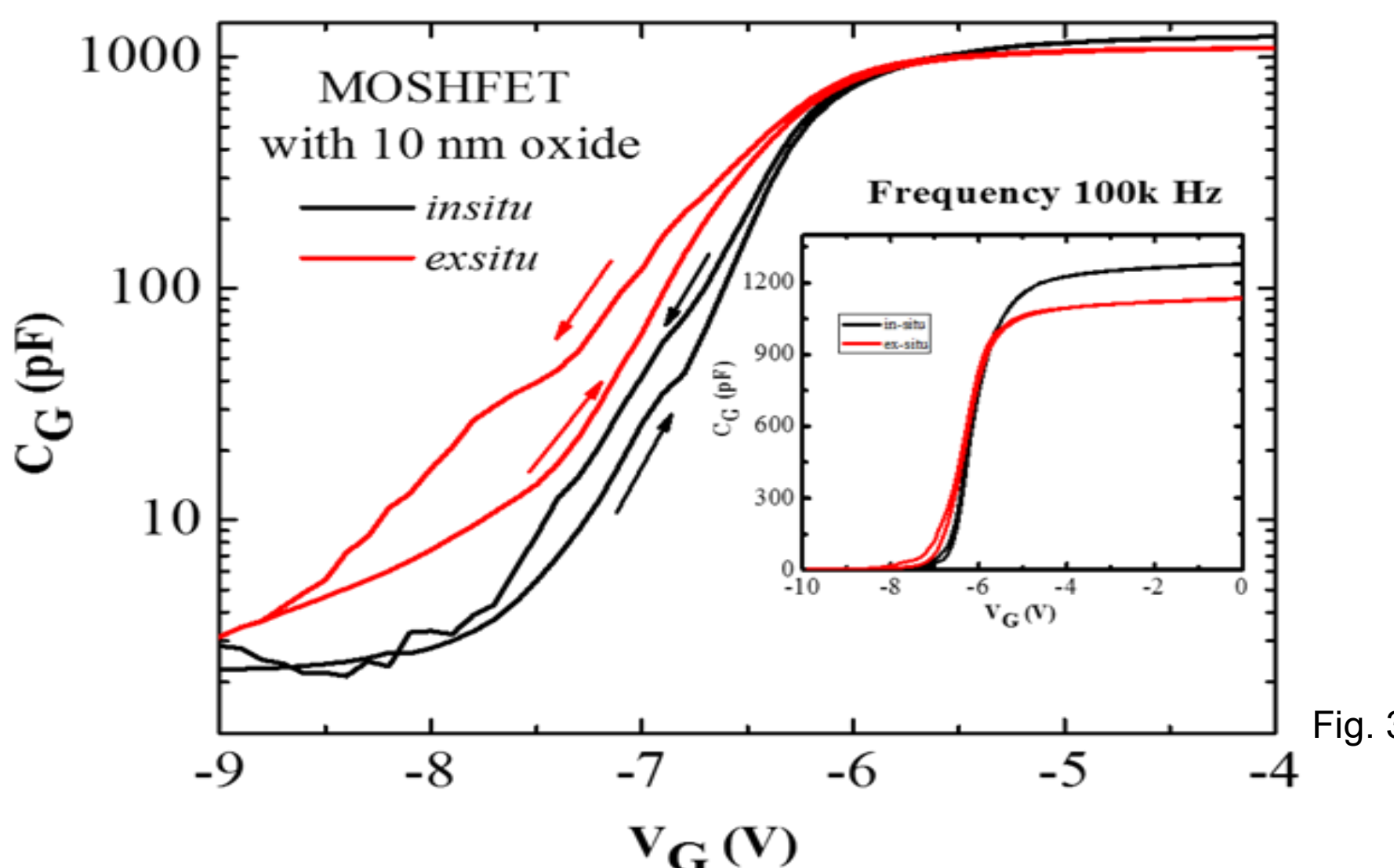
- The system measures the hysteresis and frequency dependent C—V data. It is also used for calculating interface charges in the device structures,

Data Analysis

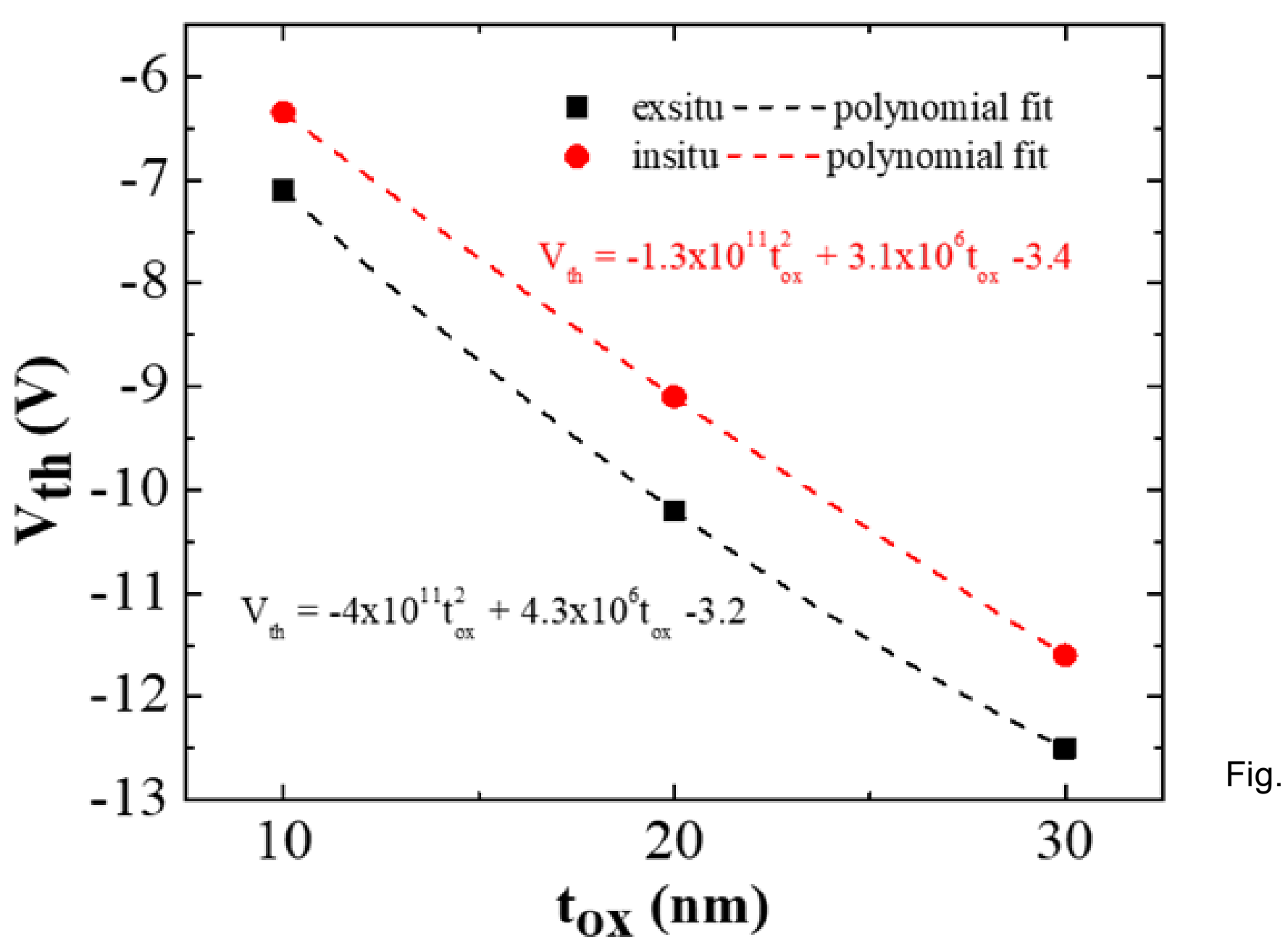


- From Fig. 2 it shows that the capacitance in accumulation region of C-V curve decreases with the increase similar oxide thickness,
- The threshold voltage shift is smaller associated with the in-situ process as compared to the ex-situ process.
- The capacitance of the MOSHFET structure in accumulation region grown by in-situ process is higher than the MOSFET structure grown by the ex-situ process indicating the reduction in extra charges at the oxide and AlGaN interface.

Result and Discussion



- C-V hysteresis measurements performed at 10 k Hz shows that MOSHFET growth by ex-situ process has more interfacial charges in its structure. Thus we conclude that decrease in the capacitance is due to extra charges at the interface in ex-situ grown MOSHFET structure.



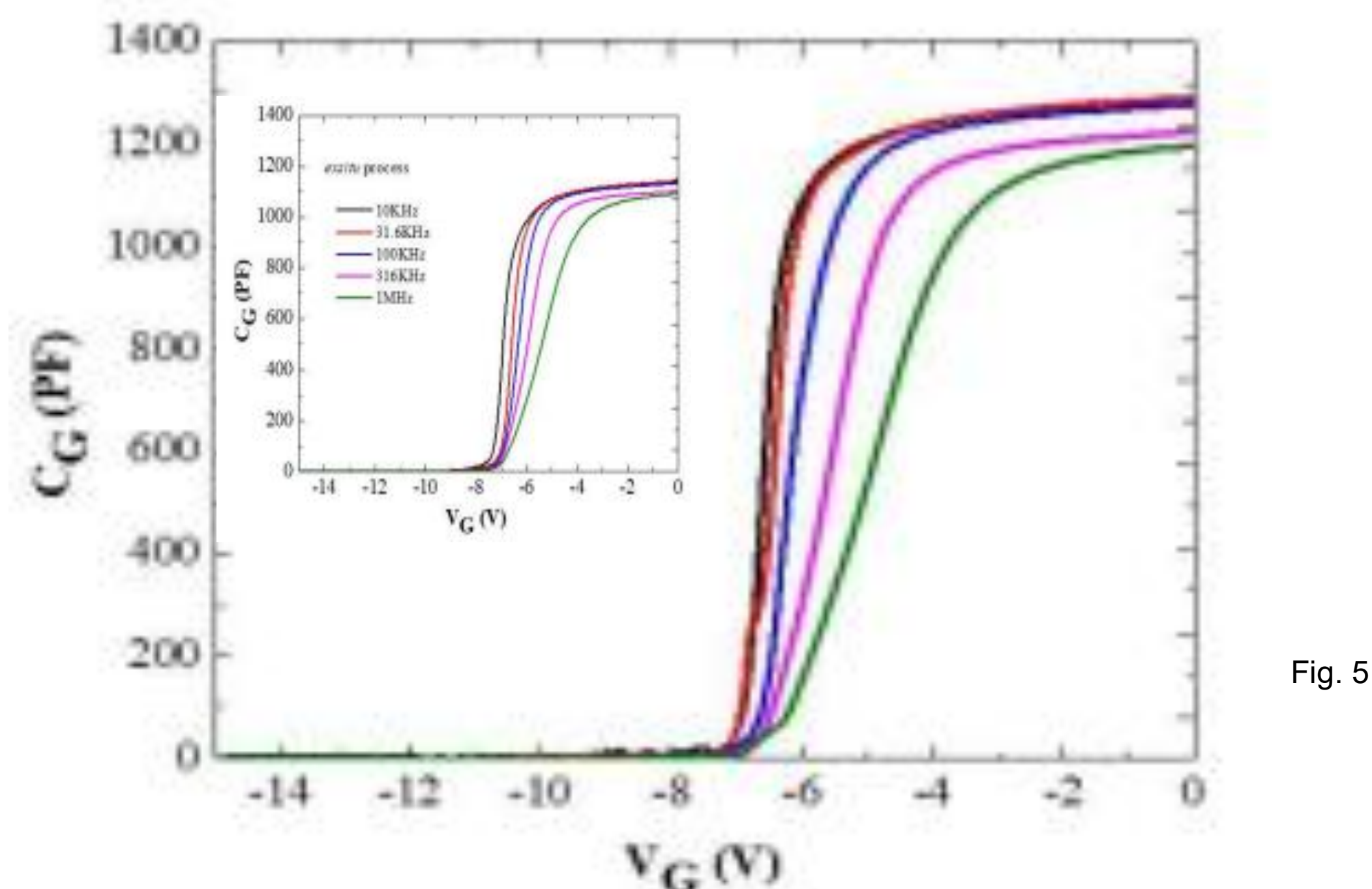
$$V_{th} = \phi_b - \phi_f - \Delta E_c - \frac{q t_{ox}^2}{2 \epsilon_{ox}} n_{ox,bulk} - \frac{q t_{ox}}{\epsilon_{ox}} n_{ox,intf} - q \left(\frac{t_{ox}}{\epsilon_{ox}} + \frac{t_b}{\epsilon_b} \right)$$

- Based on the above equation, V_{th} can be represented as 2nd order polynomial function as shown in Figure 5. through a polynomial fitting process of the thickness-dependent V_{th} dispersion, $n_{ox,bulk}$ and $n_{ox,intf}$ can be calculated.

	$n_{ox,bulk}$	$n_{ox,intf}$
Ex-situ	$+8.9 \times 10^{20}$	$+2.5 \times 10^{15}$
In-situ	1.5×10^{20}	-1.8×10^{15}

$$D_{it}(V_g) = \frac{C_{ox}}{q} \left(\frac{C_{LF}}{C_{ox} - C_{LF}} - \frac{C_{HF}}{C_{ox} - C_{HF}} \right)$$

- Fig. 5 shows the frequency-dependent capacitance data for both in-situ and ex-situ MOSHFET structures for a common 10 nm Ga_2O_3 layer.



- The value of D_{it} for ex-situ structure is $\sim 10^{12} \text{ cm}^{-2} \text{ eV}^{-1}$, which is reduced to $\sim 10^{11} \text{ cm}^{-2} \text{ eV}^{-1}$ for in-situ MOSFET structure which is remarkable. This reduction of $\sim 80\%$ in the interfacial trap density is most likely the main contributing factor for V_{th} improvement as a result of the in-situ process.

Structure/	HFET	MOSHFET		MOSHFET		MOSHFET	
Process		ex situ	in situ	ex situ	in situ	ex situ	in situ
t_{ox} (nm)	0	10	10	20	20	30	30
V_{th} (V)	-5	-7.1	-6.3	-10.2	-9.1	-12.5	-11.6
n_b (cm^{-2}) $\times 10^{13}$	1.25	1.28	1.32	1.24	1.42	1.4	1.18
D_{it} ($\text{cm}^{-2} \text{ eV}^{-1}$) $\times 10^{11}$	NA	22.3	5.52	75.7	8.52	49.8	8.05

Table 1. The summary of the key electrical parameters measured/calculated for HFET, in-situ and ex-situ MOSFET structures.

Conclusion

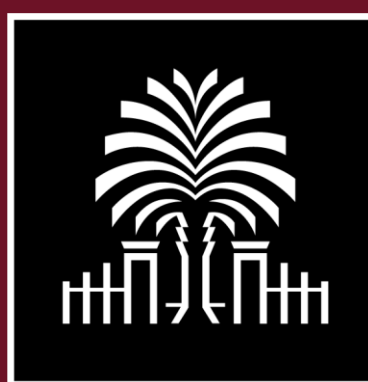
- Compared to ex-situ MOSHFET structures, the threshold voltage is improved by $\sim 10\%$ in the case of the in-situ sample, which is a critical scaling factor for power efficiency, which results in higher transconductance and hence the improvement of the gain of the FET. It should be stressed that reduction in D_{it} by an order of magnitude with the in-situ approach is the main reason for threshold voltage improvement. These results will be compared with our future study of HFET structure with Al_2O_3 capped layer, to illustrate the universality of the process.

Acknowledgement

- This work was supported by the National Science Foundation (NSF) award No. 2124624.

Reference

- Hasan, S., Jewel, M. U., Crittenden, S. R., Zakir, M. G., Nipa, N. J., Avrutin, V., ... & Ahmad, I. (2024). Reduction in density of interface traps determined by CV analysis in III-nitride-based MOSHFET structure. *Applied Physics Letters*, 124(11).



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