

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

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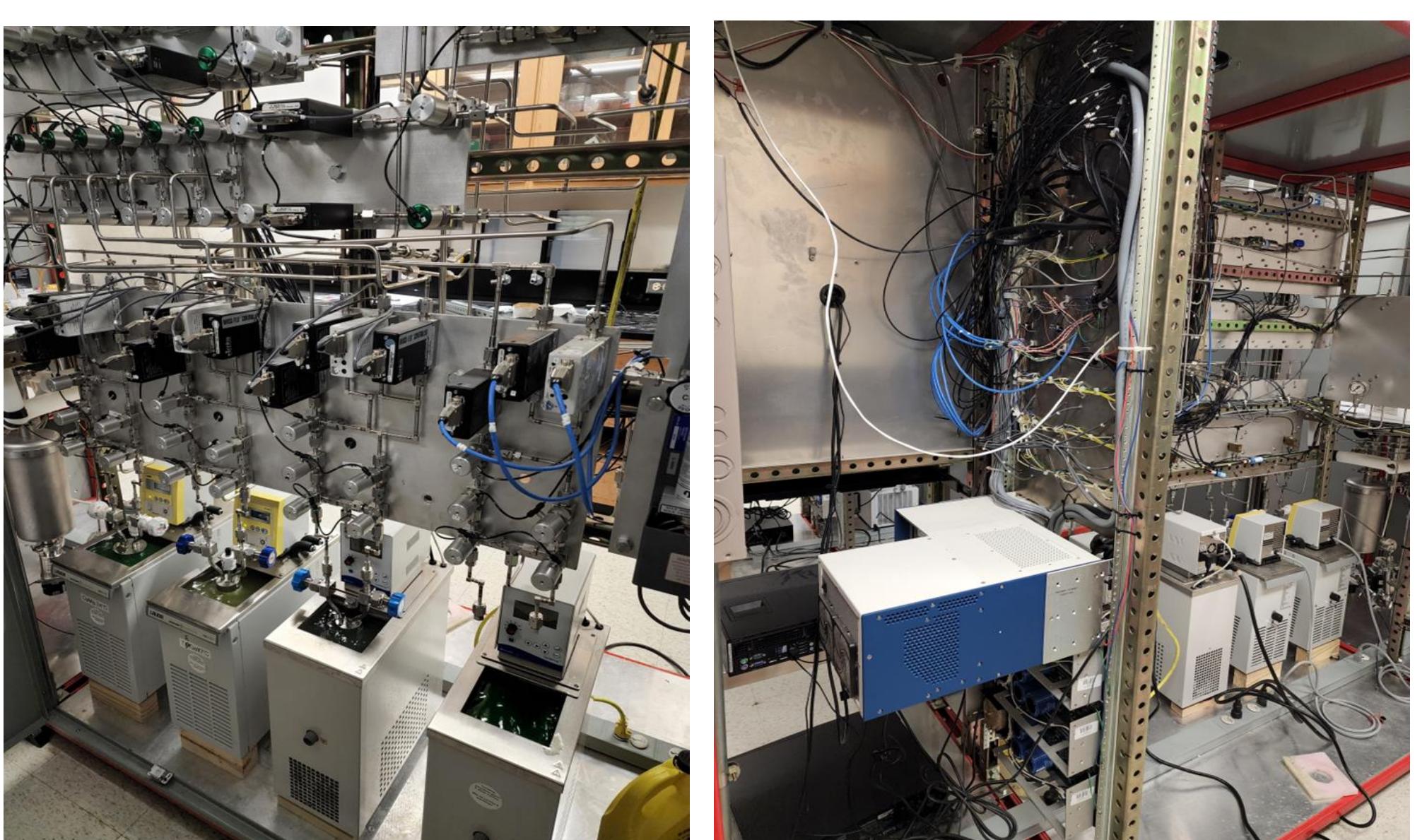
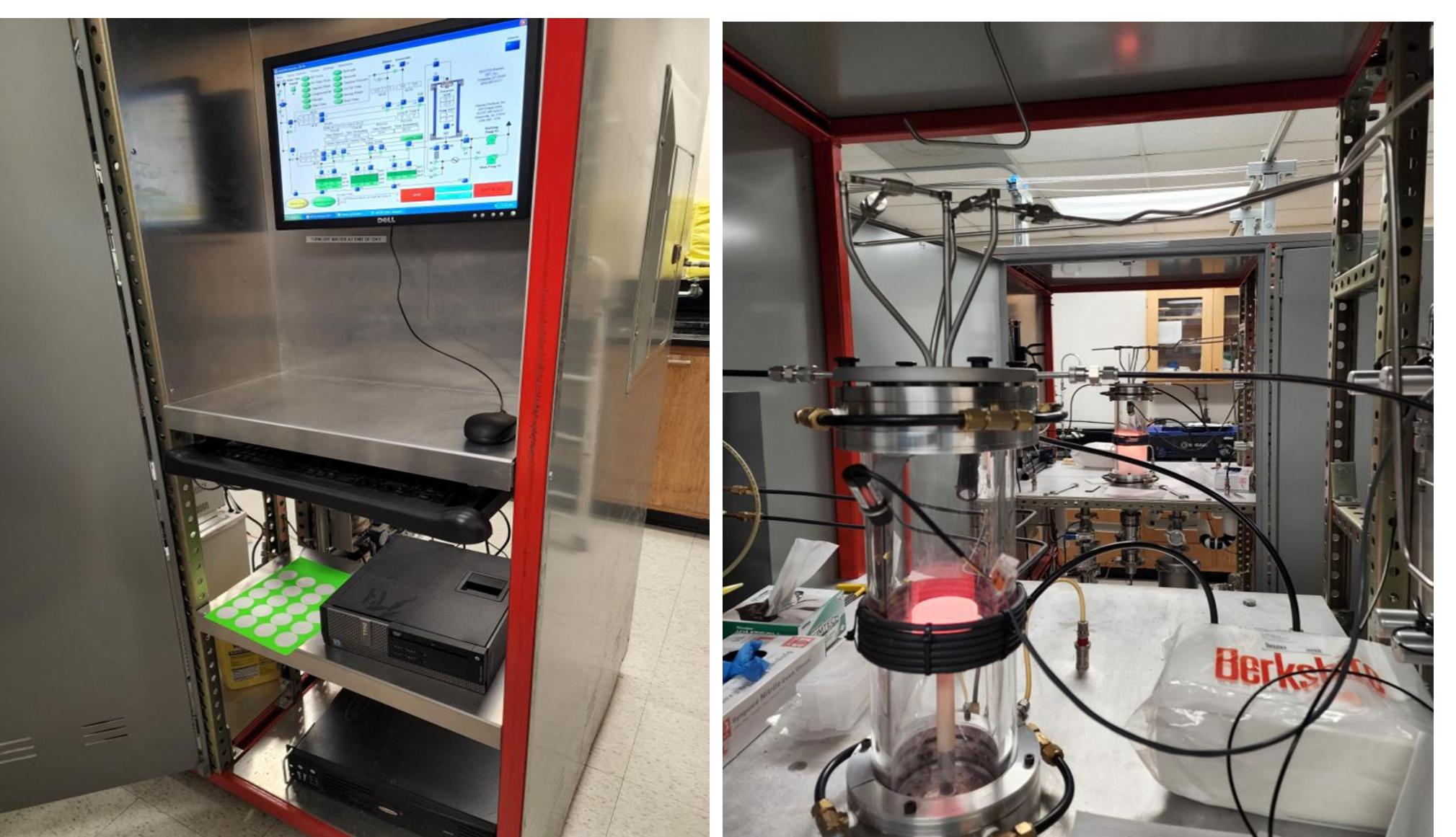
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## Introduction

- The oxide layer in MOSFET 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  $\text{Ga}_2\text{O}_3$  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 ( $\text{Ga}_2\text{O}_3$ ) 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  $\text{Ga}_2\text{O}_3$  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<sub>3</sub>), and ultra-high purity oxygen (O<sub>2</sub>) 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  $\text{Ga}_2\text{O}_3$  in order to avoid an overlap of oxygen and hydrogen species at 50 Torr.

## Schematic of HEMT Structure

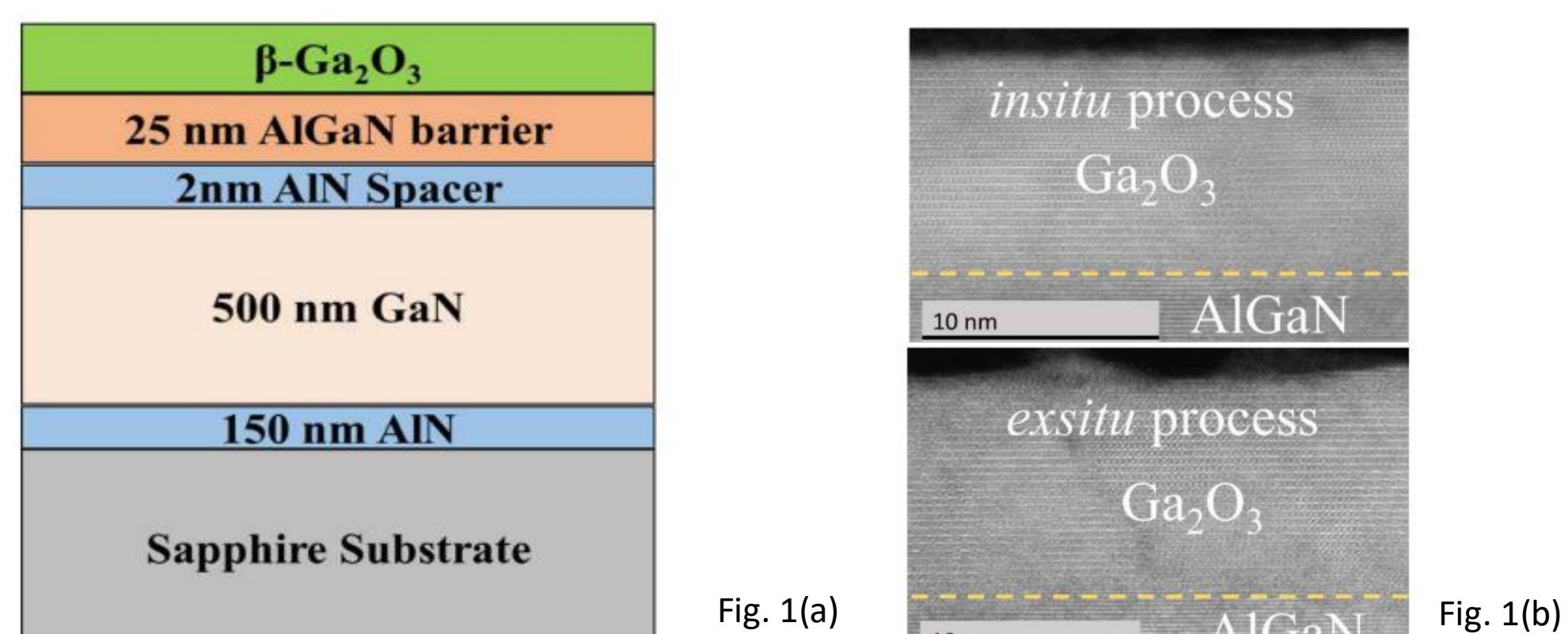
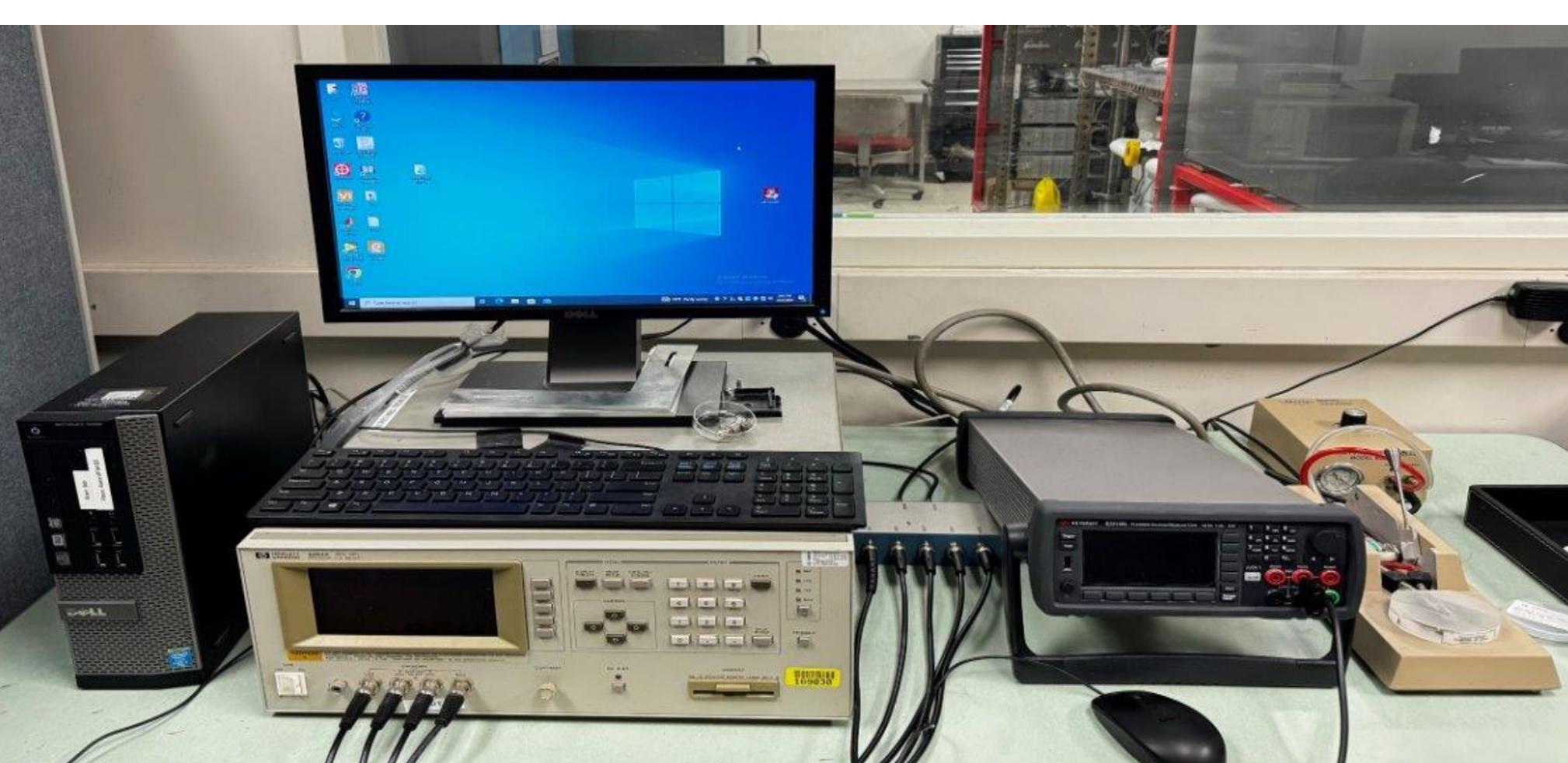


Figure 1(a) exhibits the schematic of the MOSHFET structure. Figures 1(b) shows the high-resolution transmission electron microscopy (HR-TEM) images of the barrier AlGaN and  $\text{Ga}_2\text{O}_3$  interface for a 10 nm thick  $\text{Ga}_2\text{O}_3$  MOSHFET structure with oxide layer grown by in-situ and ex-situ processes.

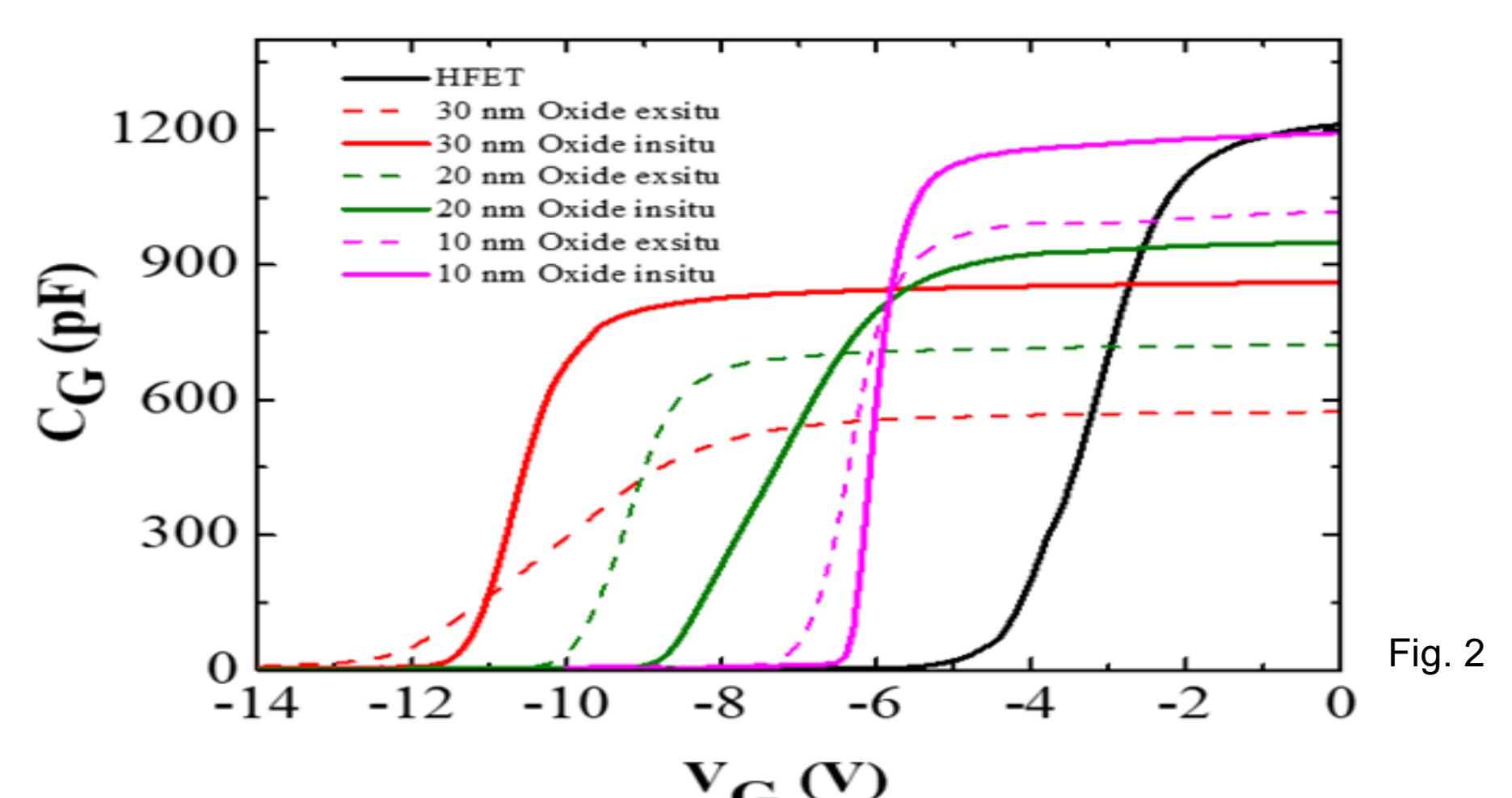
We observe no apparent defects or imperfections, such as dislocations, stacking faults, or grain boundaries, present at the interface in both in-situ and ex-situ processes.

## CV Characterization Technique



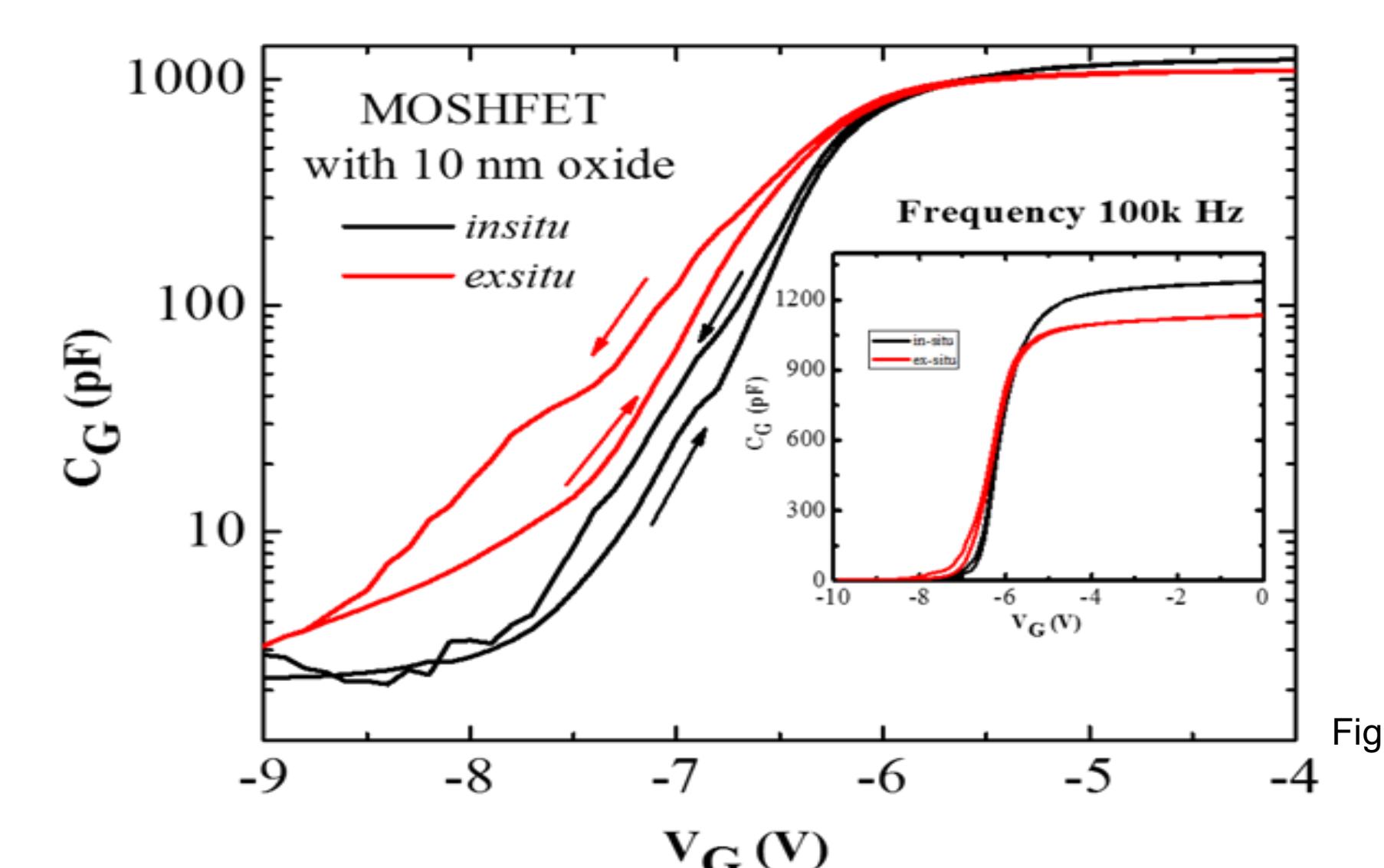
The system measures the hysteresis and frequency dependent C-V data. It is also used for calculating interface charges in the device structures,

## Data Analysis

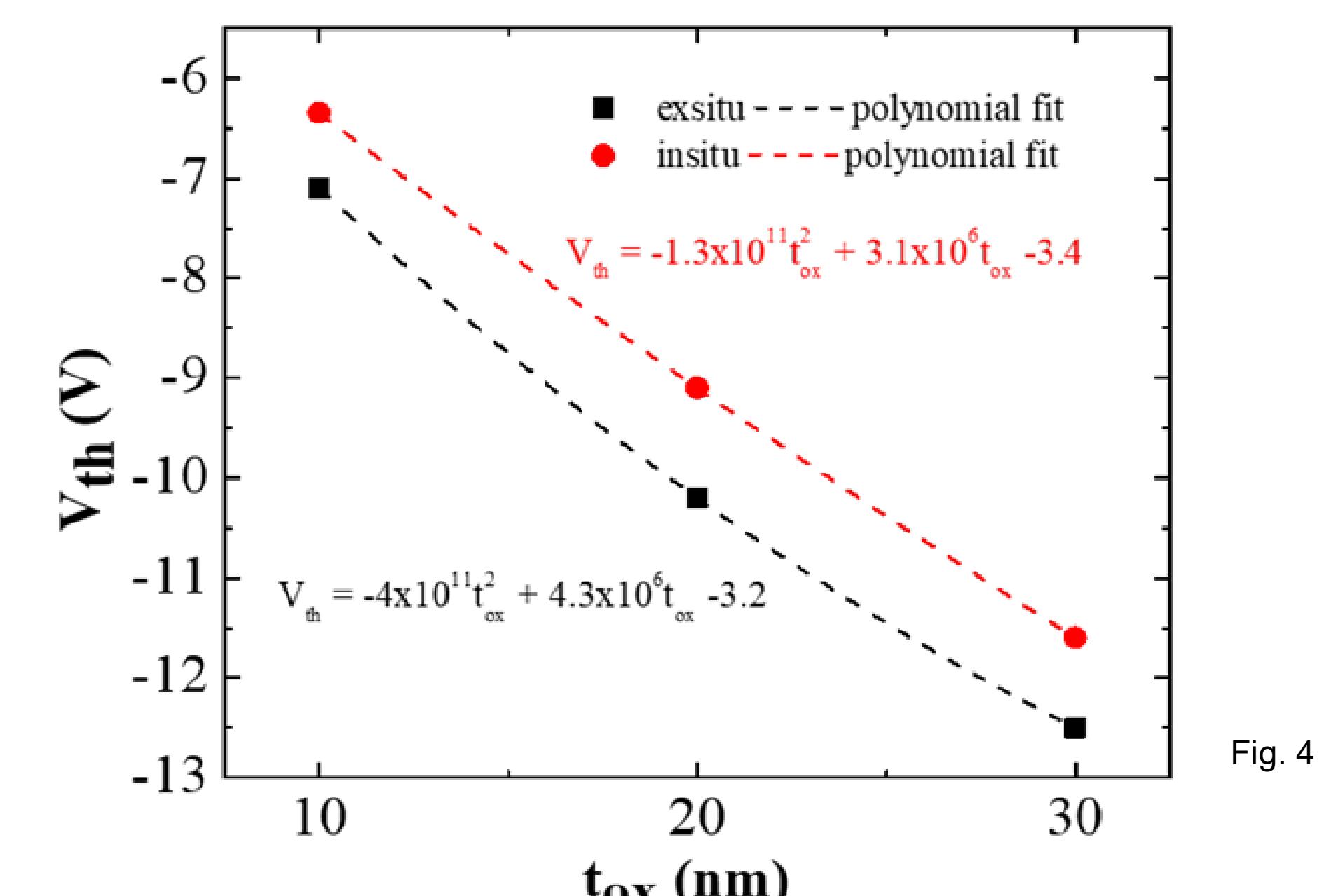


- From Fig. 2 it shows that the capacitance in accumulation region of C-V curve decreases with the increase similar oxide thickness,
- The threshold voltage shift is smaller associated with the in-situ process as compared to the ex-situ process.
- The capacitance of the MOSHFET structure in accumulation 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.



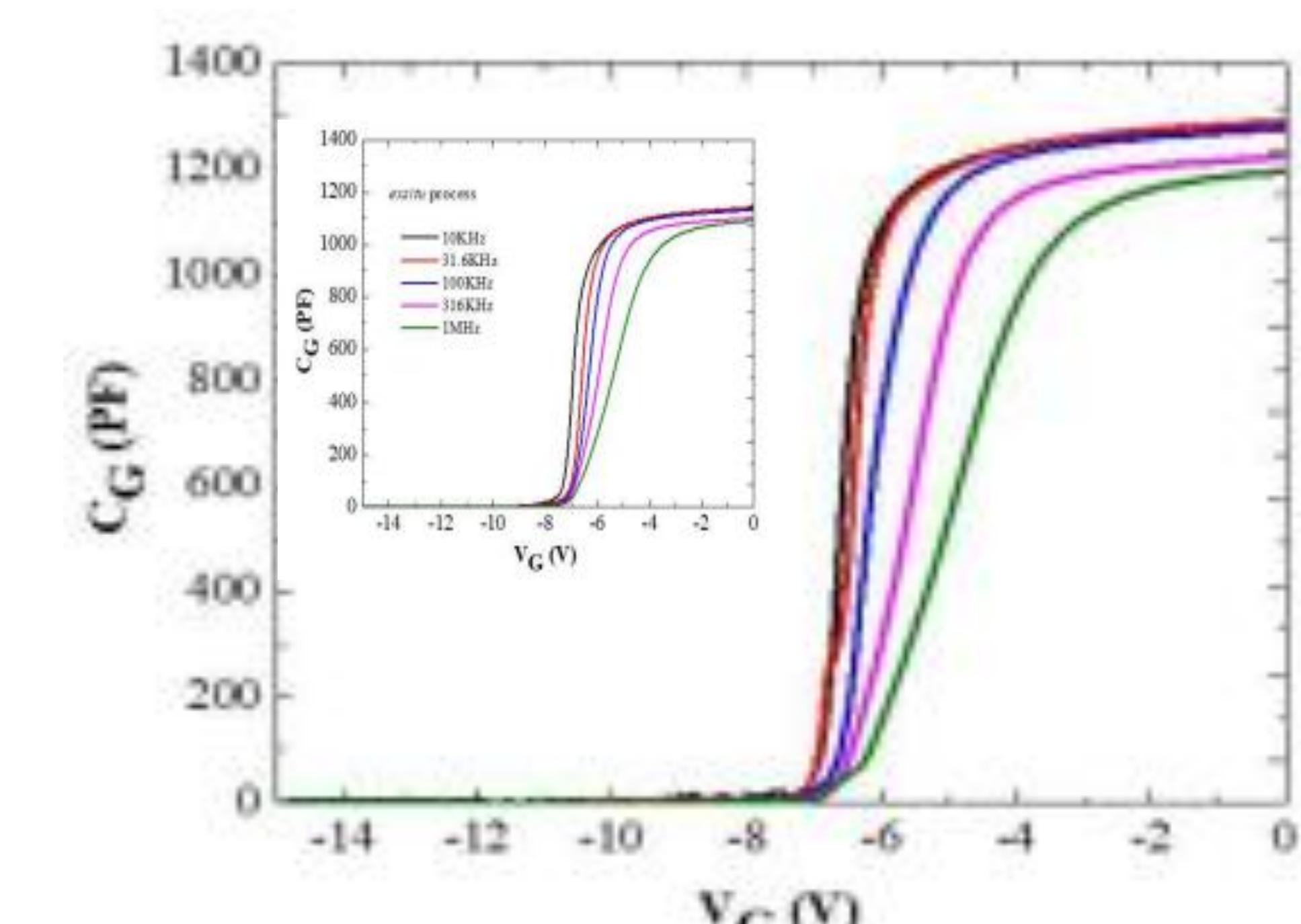
$$V_{th} = \varphi_b - \varphi_f - \Delta E_C - \frac{q t_{ox}^2}{2 \epsilon_{ox}} n_{ox,bulk} - \frac{q t_{ox}}{\epsilon_{ox}} n_{ox,intf} - q \left( \frac{t_{ox}}{\epsilon_{ox}} + \frac{t_b}{\epsilon_b} \right)$$

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	$1.5 \times 10^{20}$	$-1.8 \times 10^{15}$

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

Fig. 5 shows the frequency-dependent capacitance data for both in-situ and ex-situ MOSHFET structures for a common 10 nm  $\text{Ga}_2\text{O}_3$  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/ Process	HFET		MOSHFET		MOSFET	
	ex situ	in situ	ex situ	in situ	ex situ	in situ
$t_{ox}$ (nm)	0	10	10	20	20	30
$V_{th}$ (V)	-5	-7.1	-6.3	-10.2	-9.1	-12.5
$n_s$ ( $\text{cm}^{-3}$ )	$1.25 \times 10^{13}$	$1.28 \times 10^{13}$	$1.32 \times 10^{13}$	$1.24 \times 10^{13}$	$1.42 \times 10^{13}$	$1.18 \times 10^{13}$
$D_{it}$ ( $\text{cm}^{-2} \text{ eV}^{-1} \times 10^{11}$ )	NA	22.3	5.52	75.7	8.52	49.8

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  $\text{Al}_2\text{O}_3$  capped layer, to illustrate the universality of the process.

## Acknowledgement

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## 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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