

# AlGaN/GaN microwave HEMT transistors on monocrystalline GaN substrates (PoI-HEMT)

PBS1/A3/9/2012



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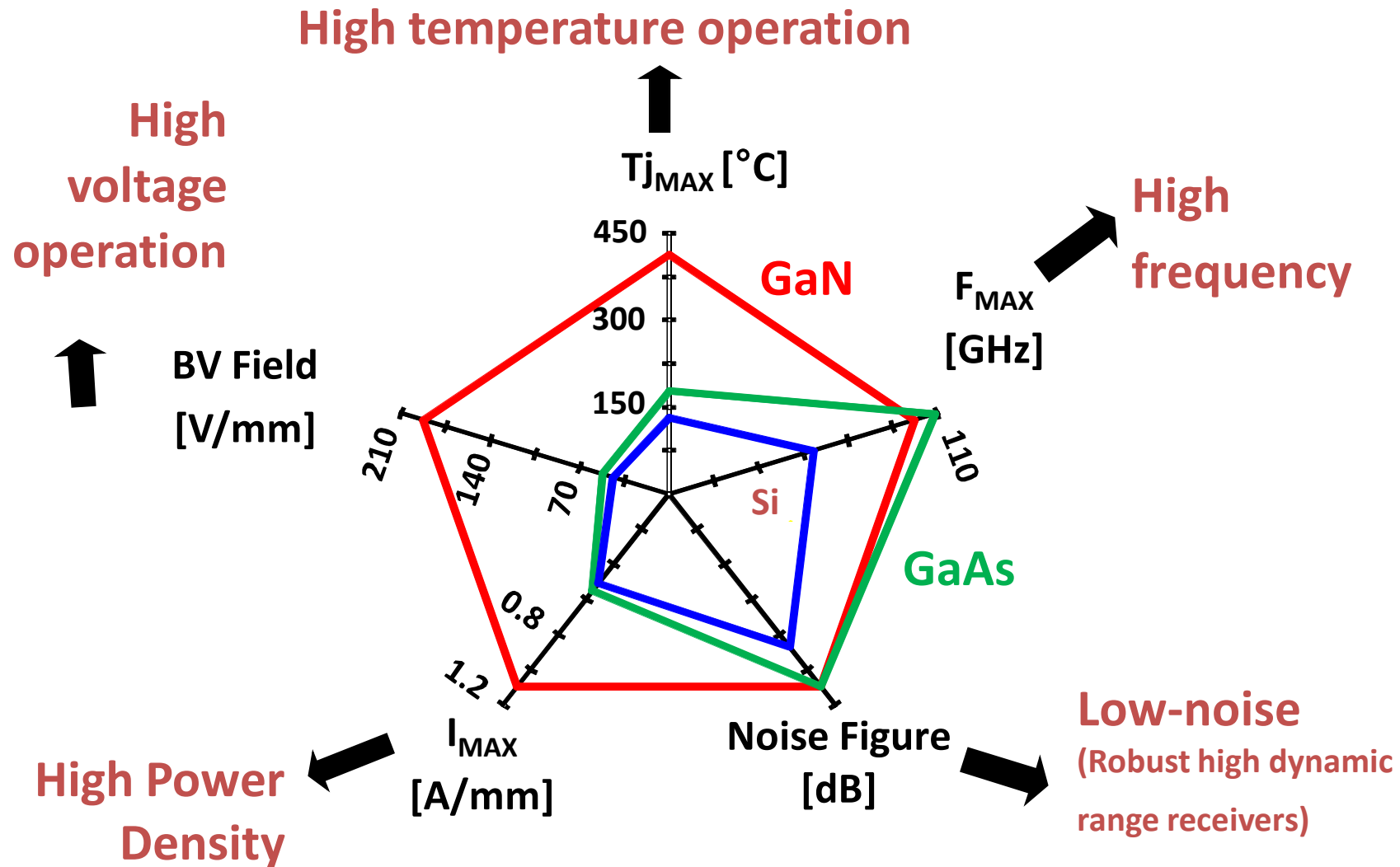
Department of Micro- and Nanotechnology of Wide Bandgap Semiconductors

# Plan of Presentation



- 1. Motivation**
- 2. Goal and scope**
- 3. Project progress**

# Motivation



# Motivation



## GaN

Wide  $E_g$

High  $E_B$

High  $v_{sat}$

## AlGaN / GaN

Heterojunction

High  $n$

High  $\mu_n$

- High output power  $P_{out}$
- High threshold frequency  $f_t = \frac{g_m}{2\pi C_{gs}} = \frac{v_{sat}}{l_g}$
- High power added efficiency  $PAE = \frac{P_{out} - P_{in}}{P_{DC}}$
- High operation temperature  $T_{max}$

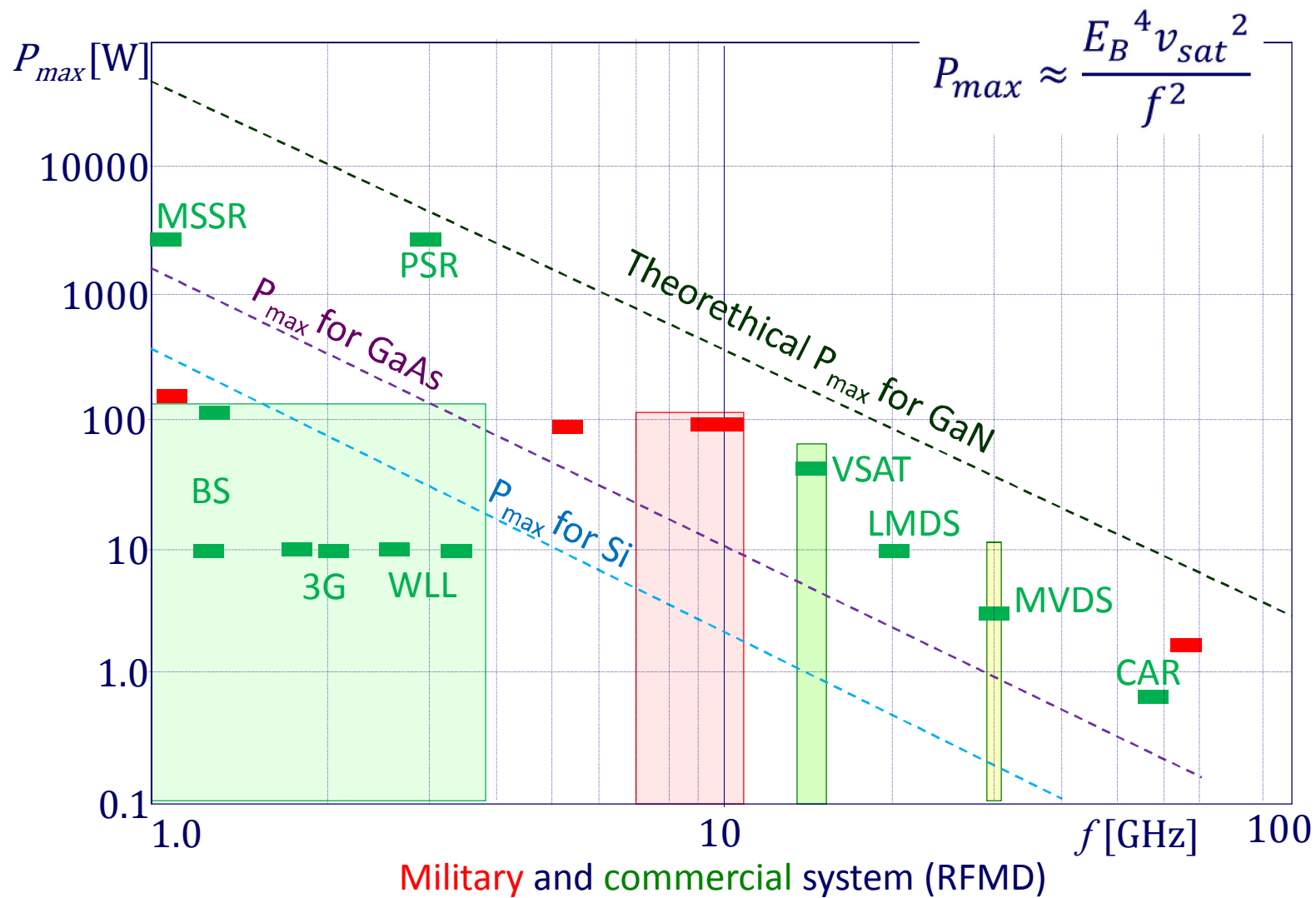
$I_D \uparrow$

$R_{on} \downarrow$



- ✓ Low cooling demand
- ✓ Compact size
- ✓ Possibility of large scale integration

# Motivation



# Aim and scope of work

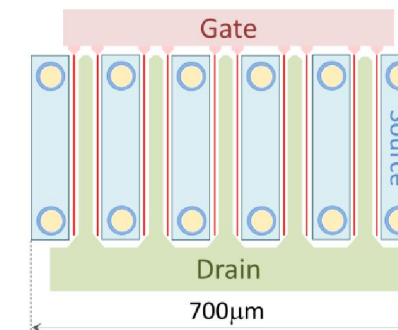
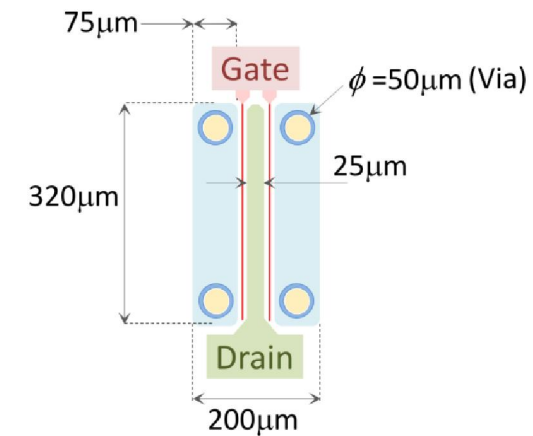


## Microwave S-band AlGaIn/GaN HEMTs on 1.5" bulk GaN substrates

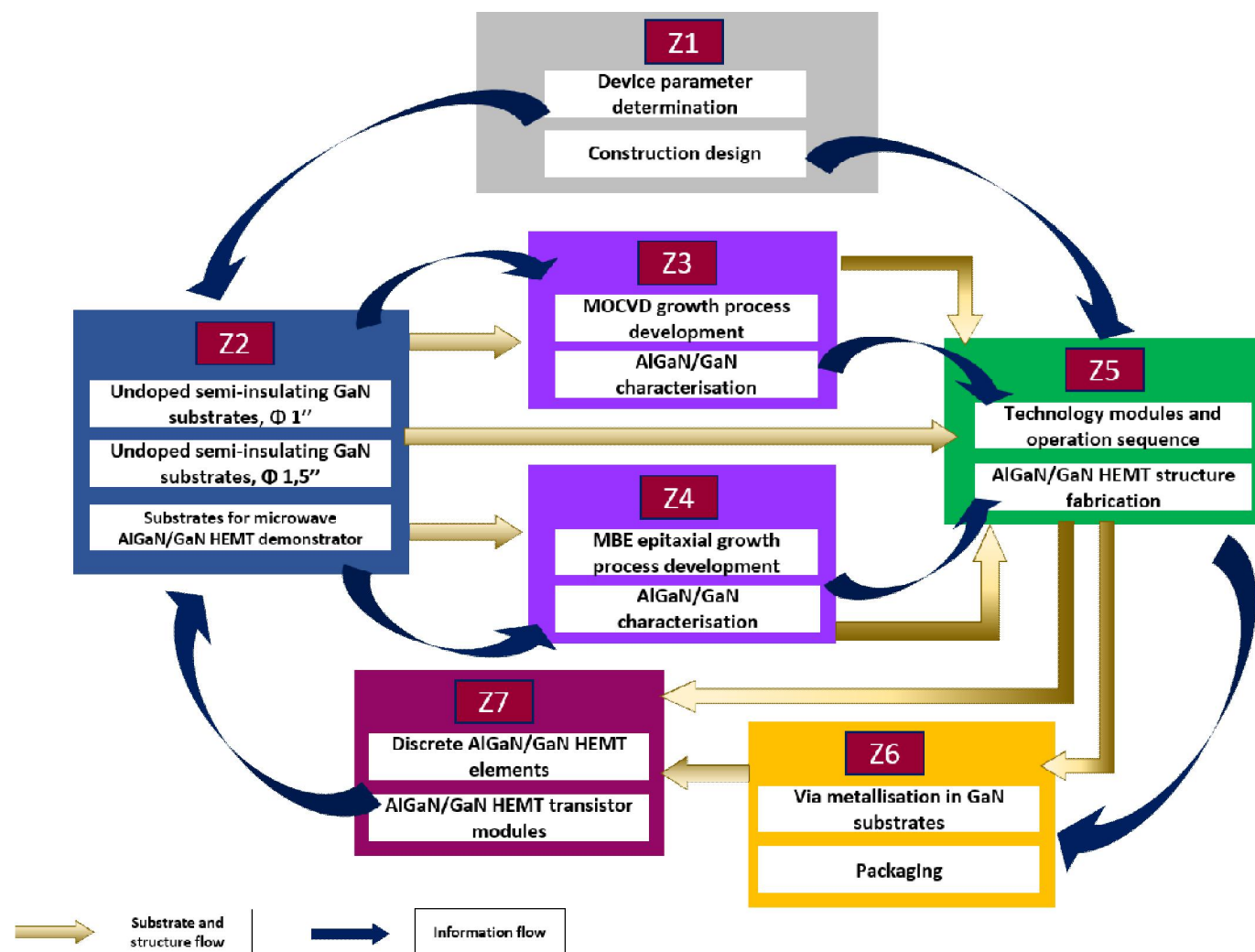
### Target single HEMT cell/module parameters

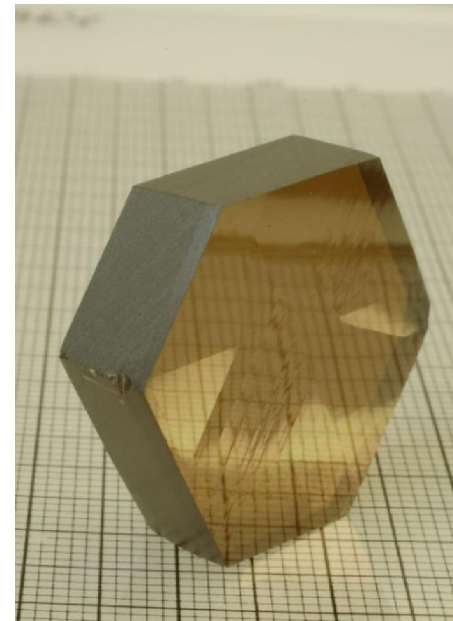
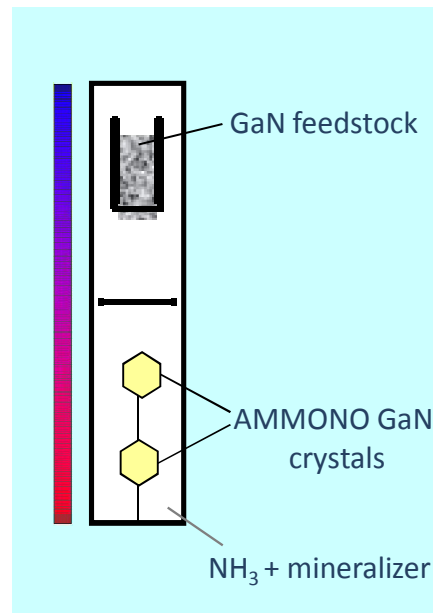
	Cell	Module
Gate length $l_g$	$0.3 \div 0.6 \mu\text{m}$	-
Saturation current $I_{\text{Dsat}}$ ( $V_{\text{DS}}=5\text{V}$ , $V_{\text{GS}}=0\text{V}$ )	0.5A	2.5A
$I_{\text{Dsat}}/w_g$	$\sim 0.8\text{A/mm}$	-
Breakdown voltage $V_{\text{DSBR}}$	$> 70\text{V}$	$> 70\text{V}$
$V_{\text{GS}}$ range	$-8 \div 0\text{V}$	-
Threshold voltage $V_p$	$\sim -3\text{V}$	-
Input capacitance $C_{\text{GS}}$	$\leq 0.8\text{pF}$	$\leq 5\text{pF}$
Output capacitance $C_{\text{DS}}$	$\leq 0.18\text{pF}$	$\leq 1\text{pF}$
Band	up to 6GHz	up to 4GHz
Output power $P_{1\text{dB}}$ , $U_{\text{DS}}=28\text{V}$ , $I_{\text{DQ}}=100\text{mA}$	-	12W
Small signal gain $G_{\text{ss}}$	15dB	14dB
Maximum gate current $I_{\text{Gmax}}$	0.7mA	$\leq 4\text{mA}$
Thermal resistance (flange – channel) $R_{\text{thj-c}}$	-	$5.5^\circ\text{C/W}$
Maximum junction temperature $T_j$	$200^\circ\text{C}$	$200^\circ\text{C}$

### Topology of single HEMT cell and module



# Work breakdown



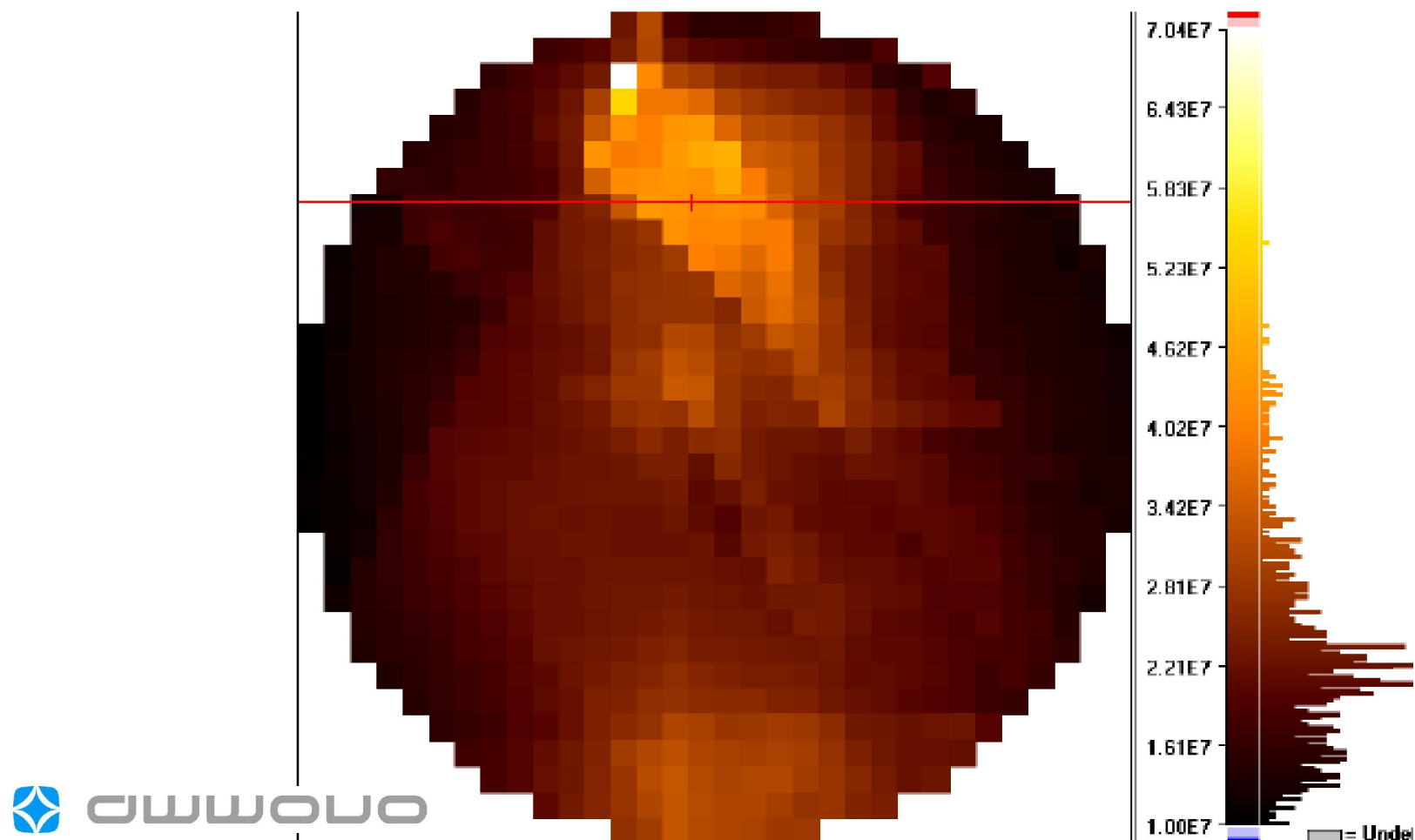


**undoped SI 1-inch GaN substrates**



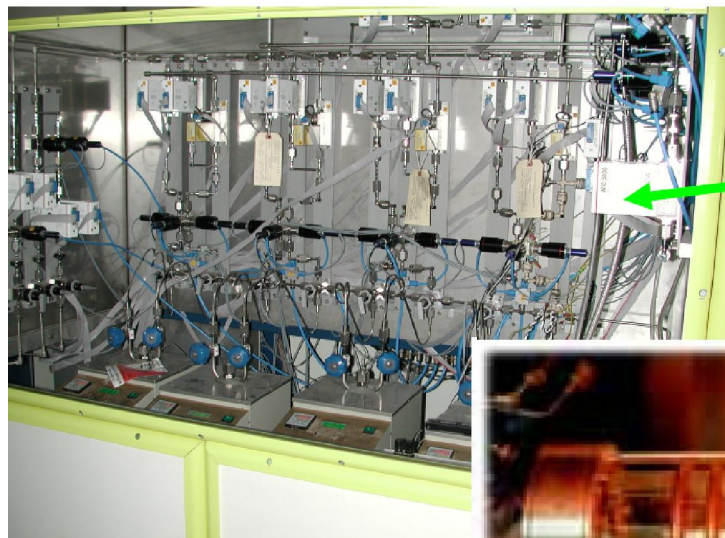


Highly resistive-GaN with reduced oxygen concentration (1.5 – inch) –  
resistivity mapping capacitive technique, time domain





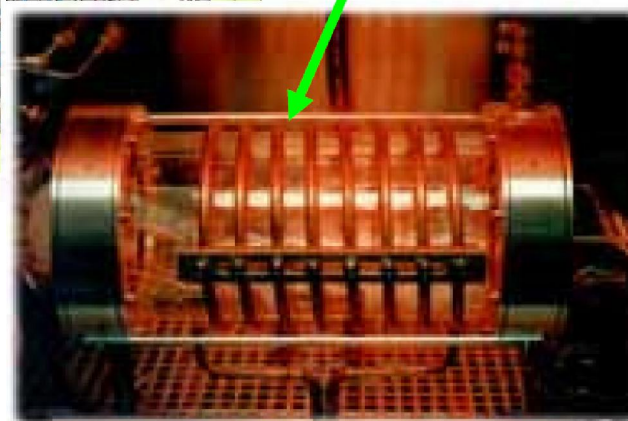
**TOP**  
**GaN** *Blue Laser Technologies*



**MOVPE**

**Gas  
system**

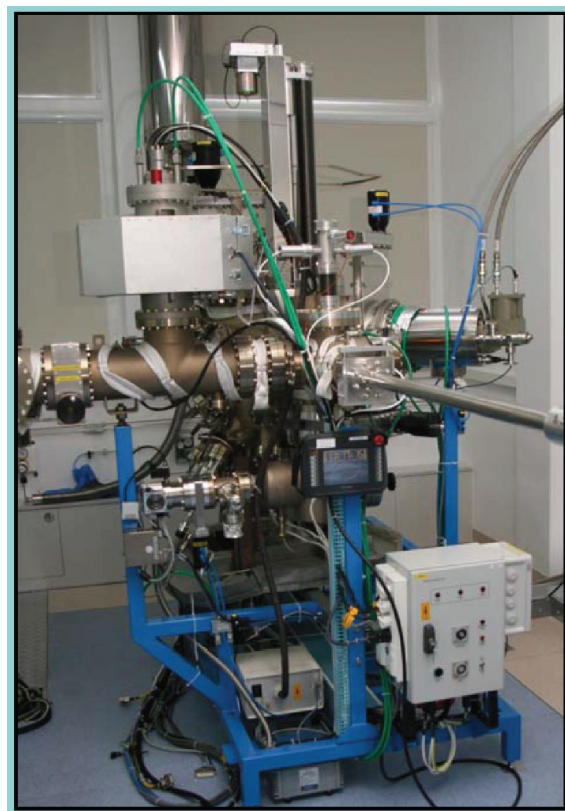
**reactor**



**Characterisation :**  
**CV, Hall, CL,**  
**AFM, XRD, SEM, TEM**



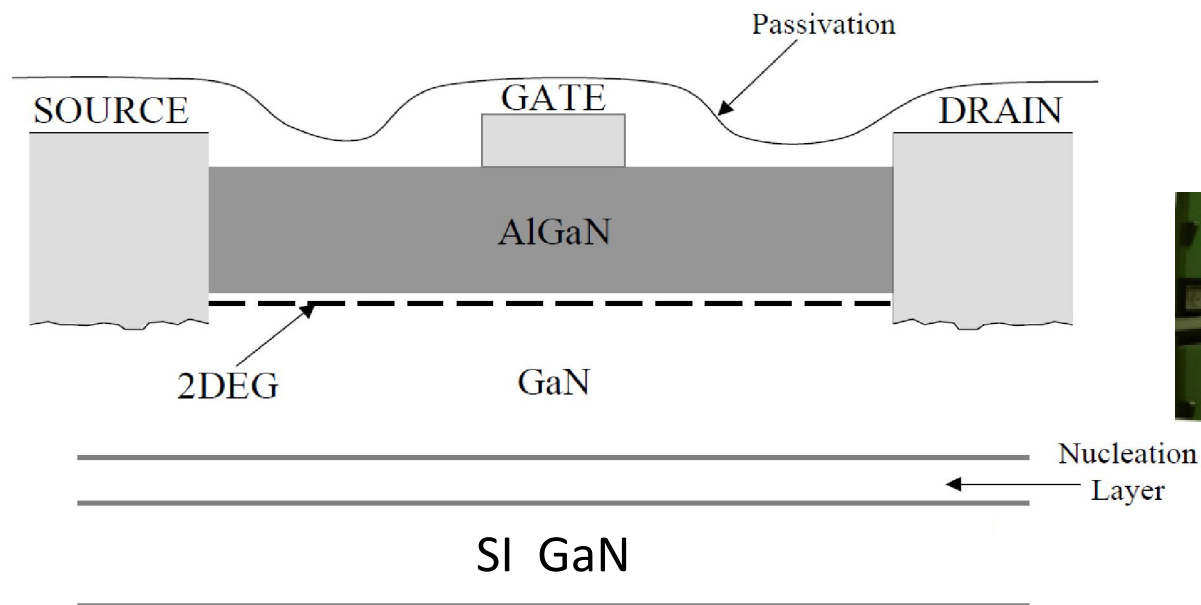
**DIVISION OF PHYSICS AND TECHNOLOGY  
OF WIDE-BAND-GAP SEMICONDUCTOR NANOSTRUCTURES  
GROUP OF MBE GROWTH OF NITRIDE NANOSTRUCTURES**



**MBE GaN Riber Compact 21**

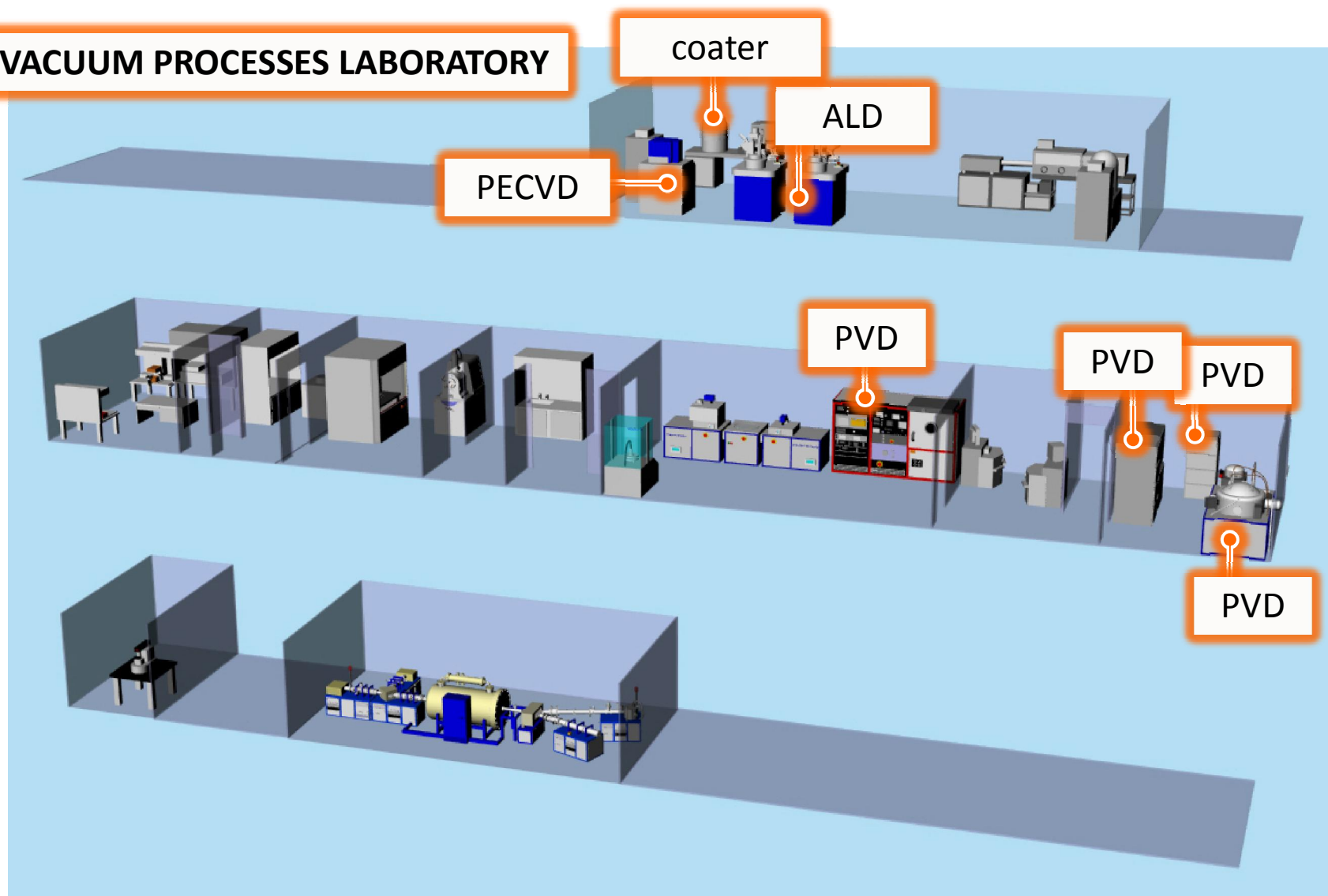


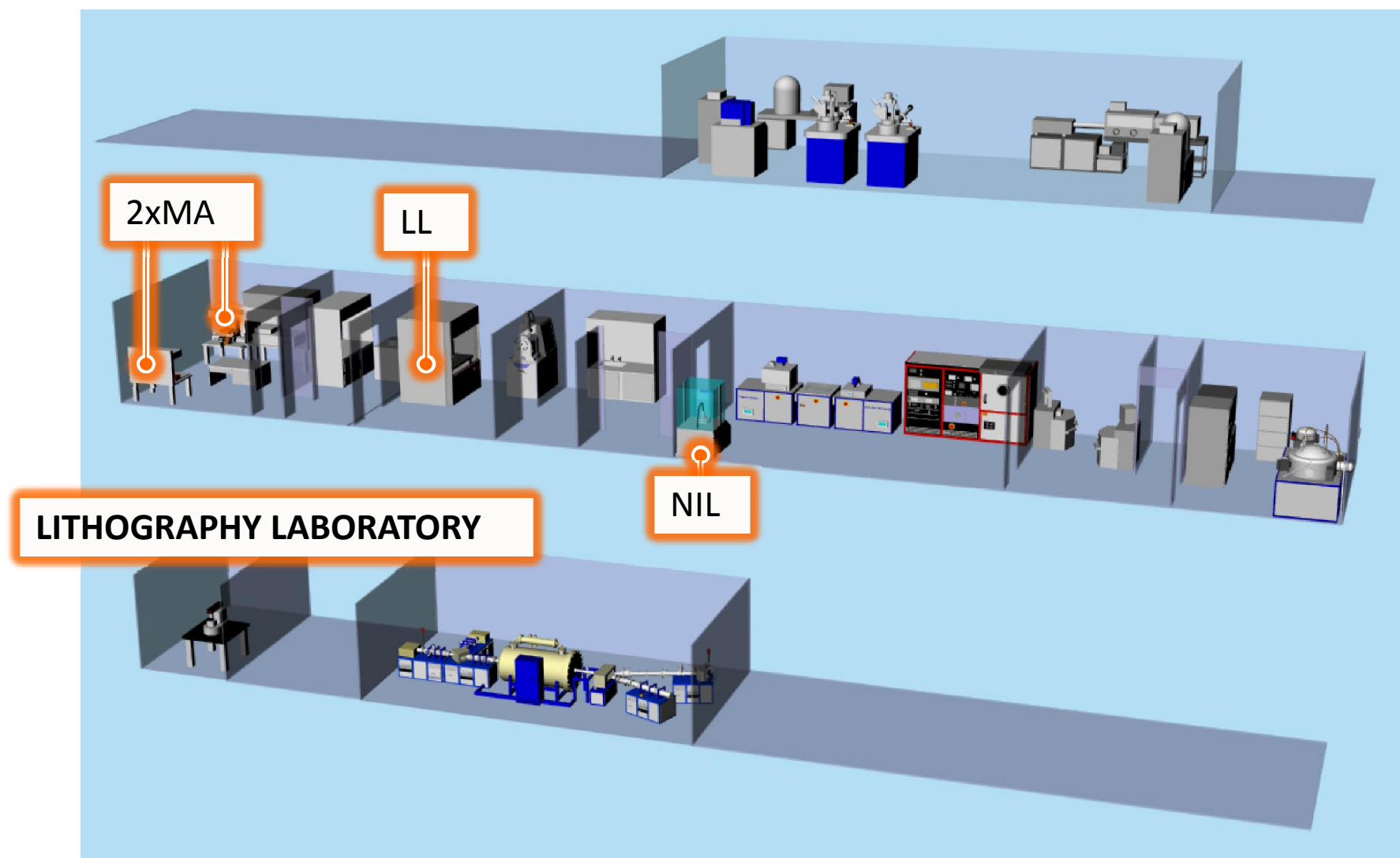
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Semiconductors



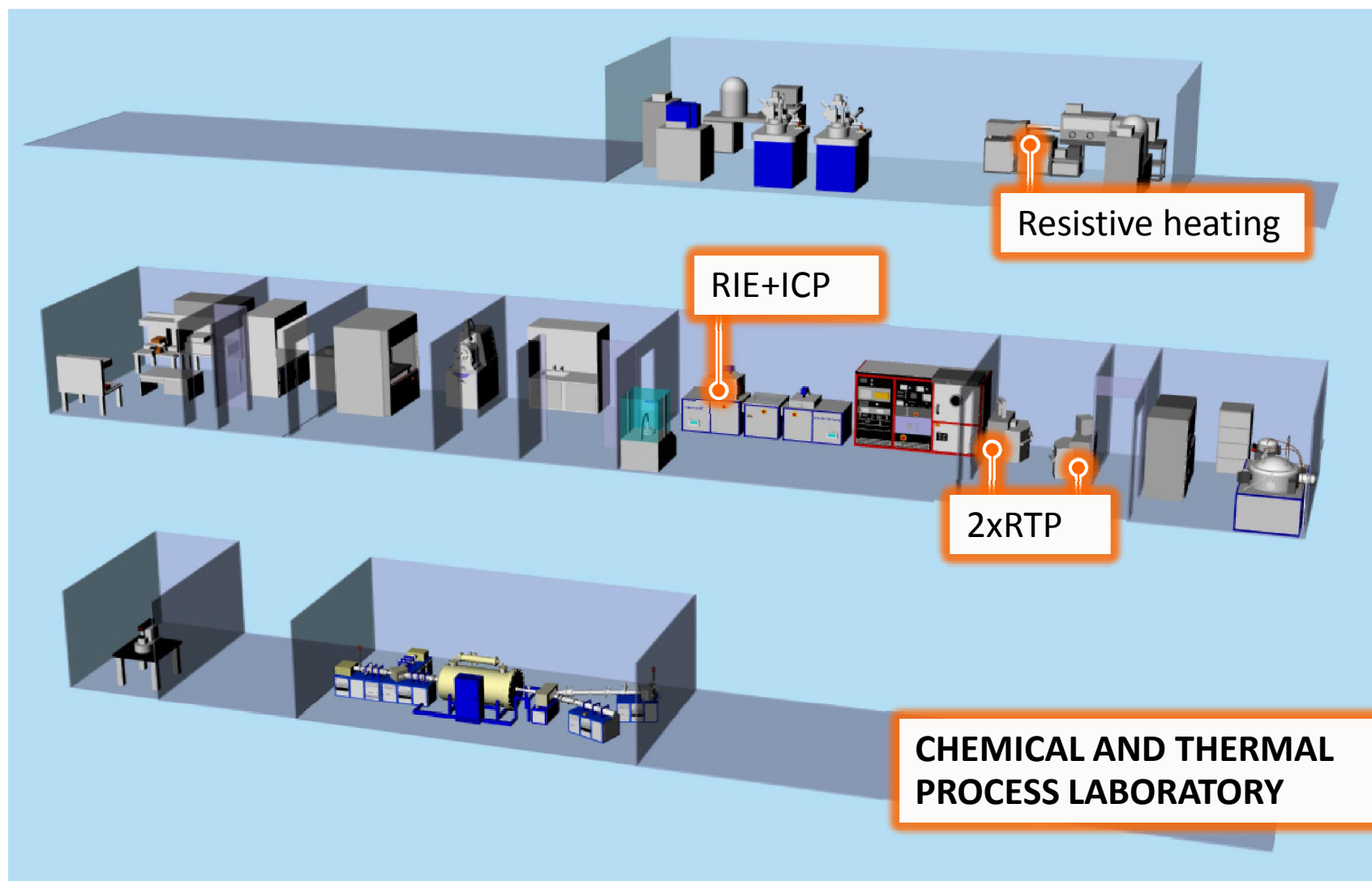


## VACUUM PROCESSES LABORATORY











**Packaging Laboratory**  
**Department of Microelectronics in Kraków**



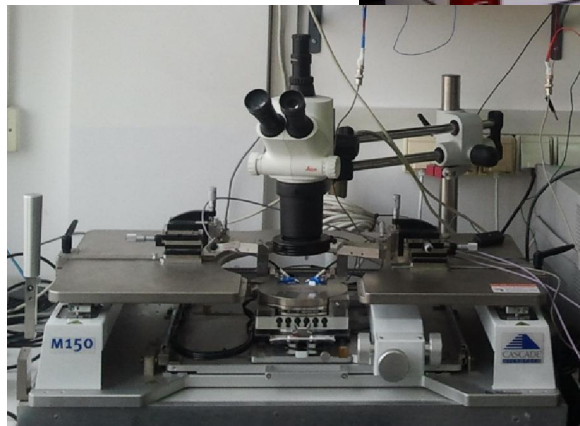




INSTYTUT RADIOELEKTRONIKI  
POLITECHNIKA WARSZAWSKA

## Microvawe Laboratory

### Microwave and Radiolocation Engineering Division



**Network analyzer:** Agilent N5230A (50GHz), HP HP8720C (26,5 GHz), Rhode-Schwarz ZVRE (4 GHz)

**Spectrum analyzer:** Agilent E4407B, Anristu MS710C

**Power meters:** Rhode-Schwarz NRVS, Agilent E4418B

**Digital oscilloscopes:** Tektronix TDS2022, Agilent DSO7054A

**„On-wafer” measurement system:** Cascade Microtech M150

**Thermovision camera:** Fluke Ti-25

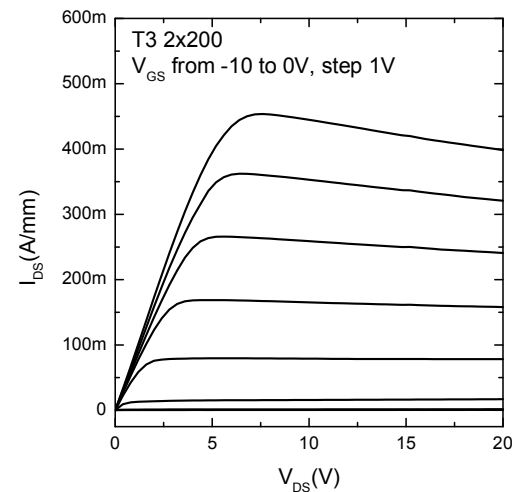
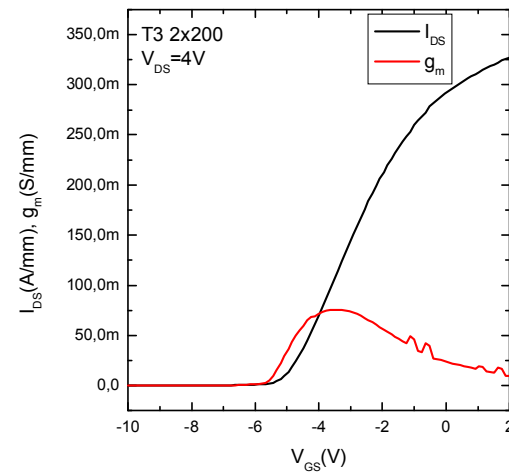
**Thermal chamber:** Binder

**Thermal response analyzer**

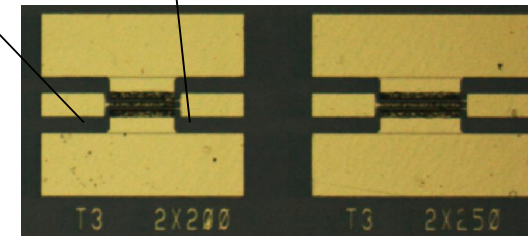
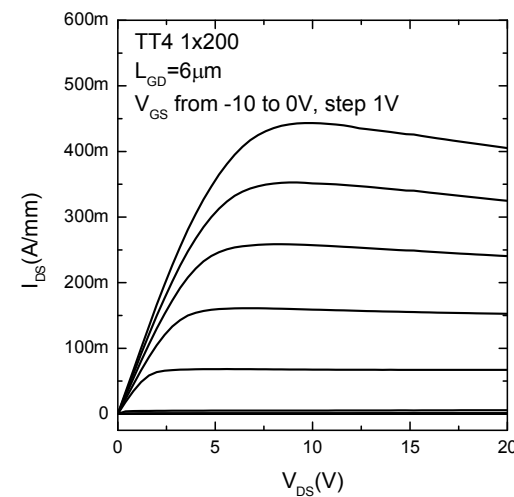
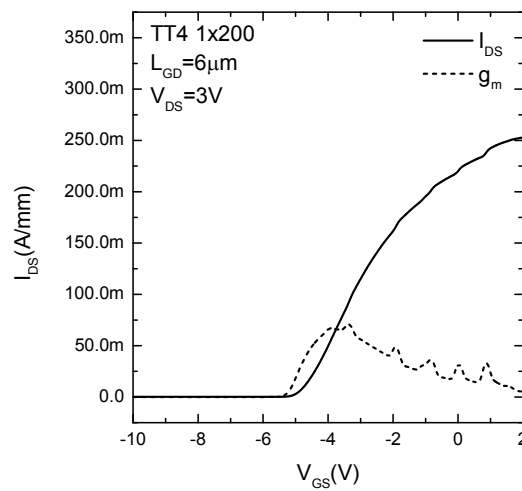
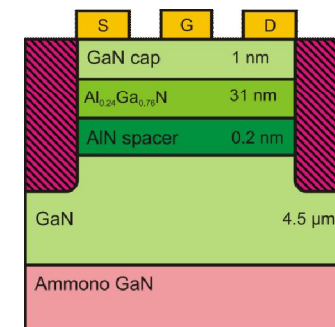
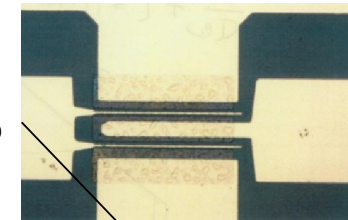
**Software:** QuickWave 3D wave simulator, Agilent ADS circuit simulator

**„on wafer” [S] matrix measurement system**

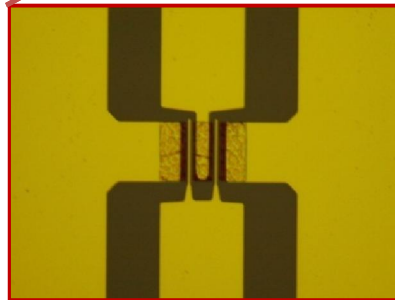
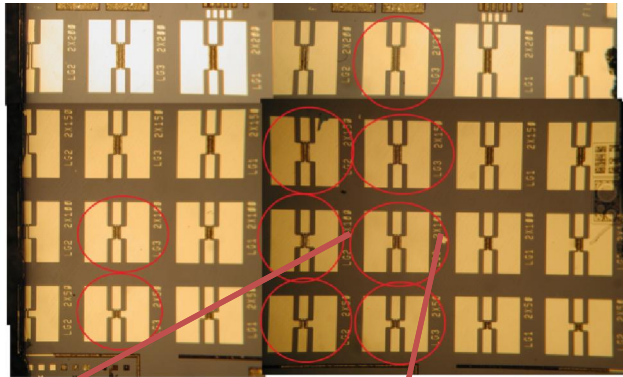
# HEMTs on highly resistive GaN substrates



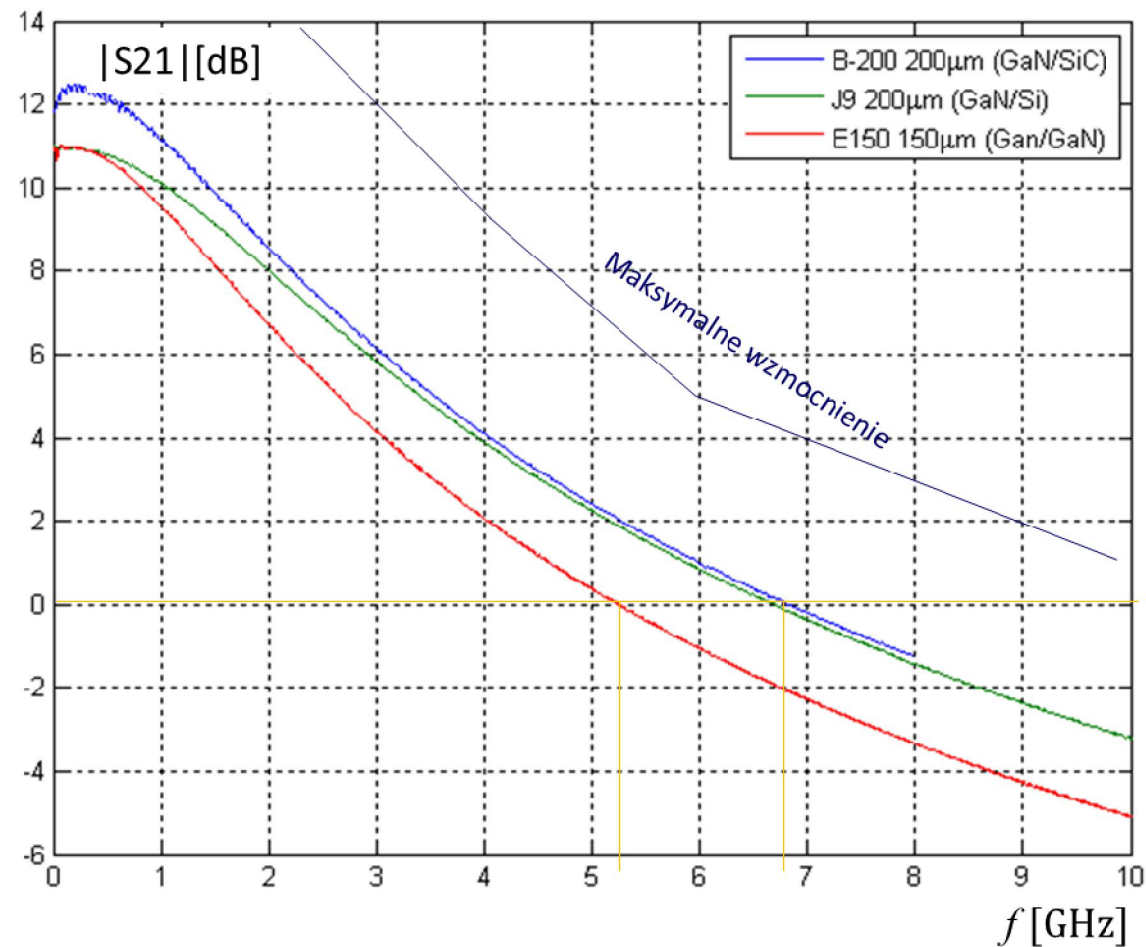
$$I_{Dsat} = 310 \text{ mA} \quad (U_{DS} = 6V \quad U_{GS} = 0V)$$



# HEMTs on highly resistive GaN substrates



Structure layout:  
Double-gate transistor  $l_g = 1 \mu\text{m}$ ;  
Saturation current:  
 $I_{\text{DSAT}}(U_{\text{GS}} = 0\text{V}, U_{\text{DS}} = 6\text{V})$  up to  $140\text{mA}$   
as a function of  $w_g$ ;  
Operation point voltage:  $U_{\text{DS}} = 6\text{V} \div 30\text{V}$ ;



Sample  $|S_{21}|$  characteristics of GaN HEMT transistors ( $l_g = 150$  and  $200 \mu\text{m}$ ) fabricated at ITE on various substrates

$|S_{21}|$  - Forward transmission coefficient (gain)

ITE GaN HEMTs maximum gain



# Conclusions & future plans



## Progress according to the workplan

			Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
<b>Z1</b>	<b>Specyfikacja parametrów materiałów i struktur oraz tranzystorów HEMT</b>	Lider:												
	Z1.1. Specyfikacja parametrów półprzewodzących podłoży GaN, struktur epitaksjalnych i przyrządowych HEMT AlGaIn/GaN	PW IRE												
	Z1.2. Modelowanie i projekt konstrukcji tranzystora mikrofalowego HEMT na bazie GaN													
<b>Z2</b>	<b>Monokrystaliczne podłoża GaN</b>													
	Z2.1. Opracowanie technologii wytwarzania niskodopowanych półprzewodzących podłoży GaN o średnicy 1"	AMMONO												
	Z2.2. Opracowanie technologii wytwarzania niskodopowanych półprzewodzących podłoży GaN o średnicy 1,5"													
	Z2.3. Wyprodukowanie i przekazanie do partnerów 30 sztuk podłoży GaN 1,5"													
<b>Z3</b>	<b>Wzrost epitaksjalny struktur AlGaIn/GaN techniką MOCVD</b>													
	Z3.1. Opracowanie procesów wzrostu epitaksjalnego MOVPE struktur tranzystorowych AlGaIn/GaN na podłożu z monokrystalicznego GaN	Top-GaN												
	Z3.2. Charakterystyka elektryczna i strukturalna struktur tranzystorowych AlGaIn/GaN na													
<b>Z4</b>	<b>Wzrost epitaksjalny struktur AlGaIn/GaN techniką MBE</b>													
	Z4.1. Opracowanie procesów wzrostu epitaksjalnego MBE struktur tranzystorowych AlGaIn/GaN na podłożu z monokrystalicznego GaN	IF PAN												
	Z4.2. Charakterystyka elektryczna i strukturalna struktur tranzystorowych AlGaIn/GaN na podłożach GaN.													
<b>Z5</b>	<b>Technologia procesów obróbki struktur HEMT AlGaIn/GaN</b>													
	Z5.1. Opracowanie technologii izolacji struktur HEMT	ITE												
	Z5.2. Opracowanie technologii wytwarzania kontaktów źródła i drenu													
	Z5.3. Opracowanie technologii wytwarzania kontaktu bramki													
	Z5.4. Opracowanie pasywacji powierzchni struktur HEMT													
	Z5.5. Opracowanie sekwencji operacji tranzystora HEMT GaN.													
<b>Z6</b>	<b>Montaż struktur HEMT AlGaIn/GaN</b>													
	6.1. Opracowanie procesów wytwarzania metalizowanych via holes w podłożach GaN	ITE												
	6.2. Montaż mikrofalowych struktur HEMT i dostarczenie elementów do Z7													
<b>Z7</b>	<b>Charakterystyka struktur i podzespołów wytworzonych w Z5 i Z6</b>													
	Z7.1. Charakterystyka elementów dyskretnych HEMT AlGaIn/GaN	PW IRE												
	Z7.2. Charakterystyka modułów tranzystorowych HEMT AlGaIn/GaN													

