

# ASM GaN: New Industry Standard Model for GaN-based RF and Power Devices

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[LINK TO DOWNLOAD ASM CODE: HTTPS://RESEARCH.SCIENCE.MQ.EDU.AU/EDAC/ASM-CODE/](https://research.science.mq.edu.au/edac/asm-code/)



# GaN has fantastic properties

HOW DO WE MAKE MOST OF IT?

## Power converters

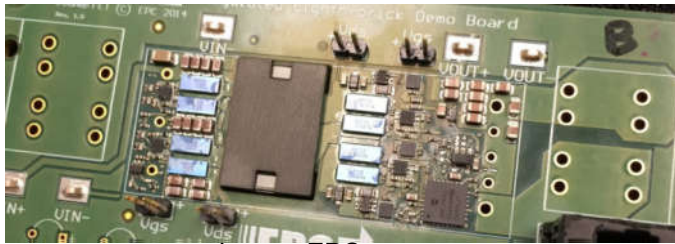
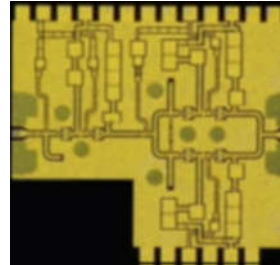
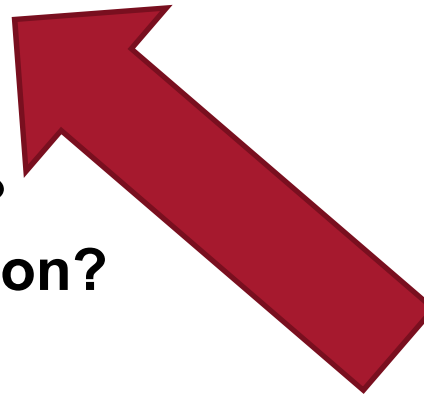


Image: EPC

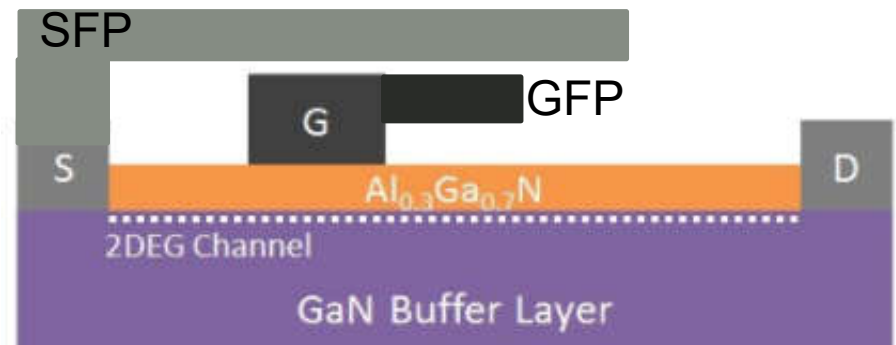
## RF PA's



**Trial and error?**  
**Rough simulation?**



## GaN device



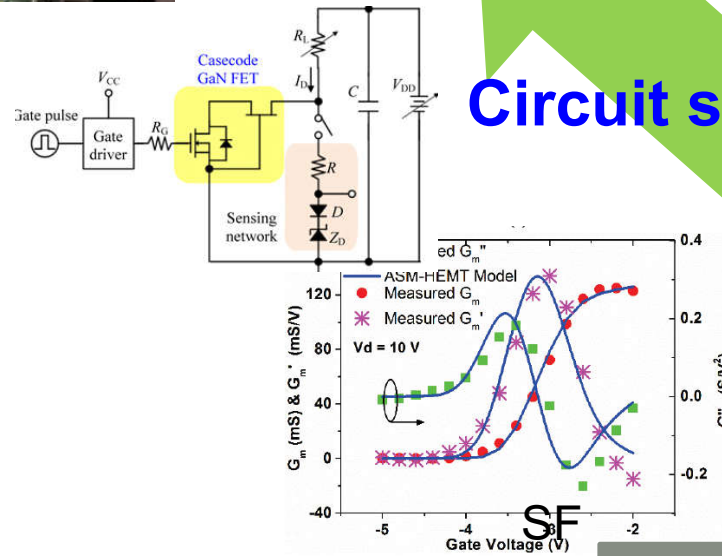
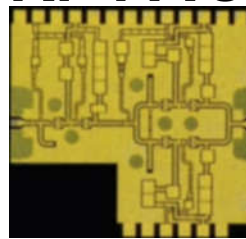
# Optimal Use of GaN

NEEDS ADVANCE MODELS

## Power converter



## RF PA's



Circuit simulations

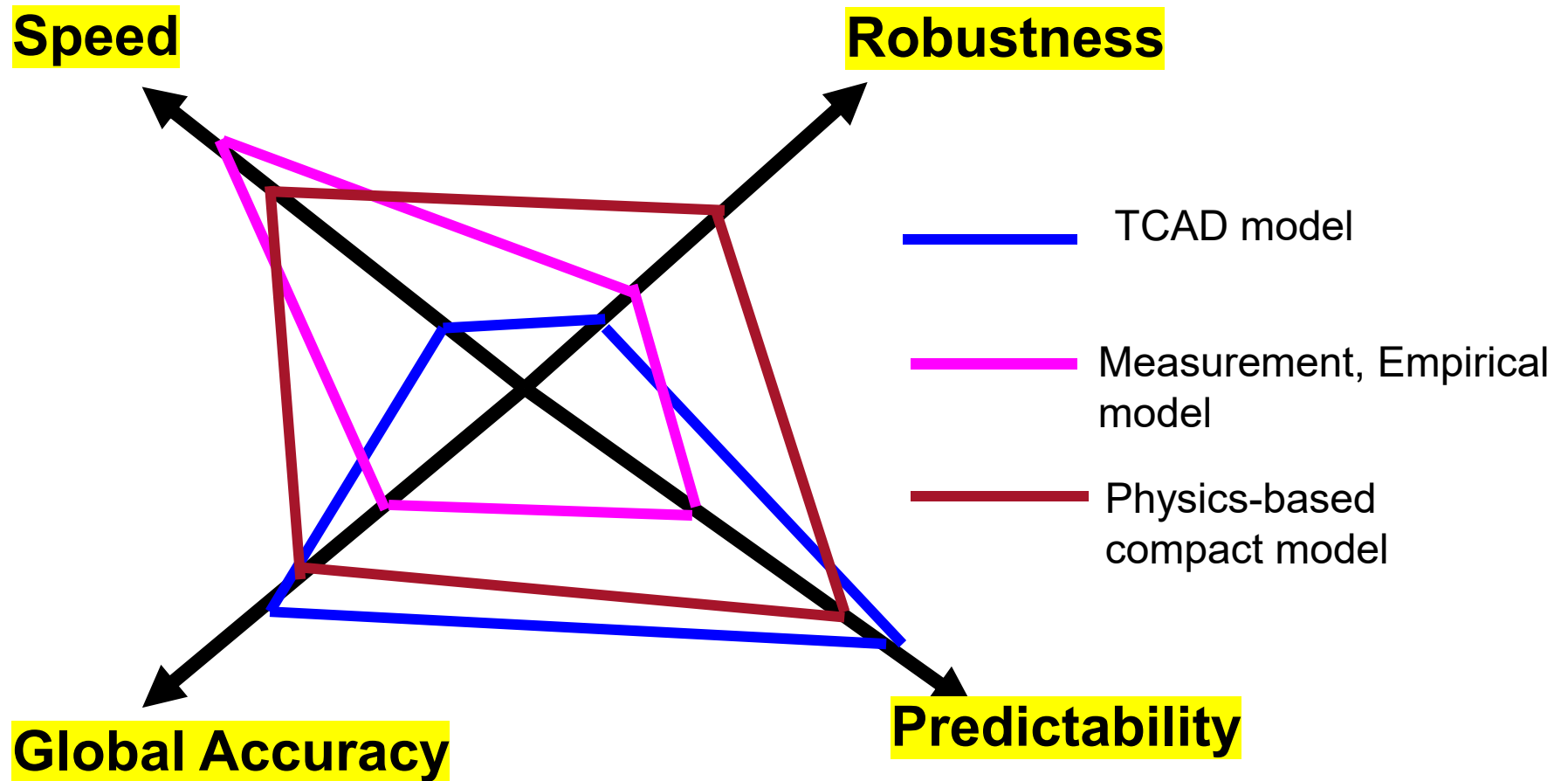
Accurate device model

GaN device



Ref. S. Khandelwal  
CSICS 2015

# Model Types and Tradeoffs



**Physics-based compact models offers the best trade-off**

# Outline

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- **Advance SPICE Model (ASM) for GaN RF and power devices**
  - Model introduction
  - Model description
  - RF device results
  - Power device Results
  - Summary

# ASM GaN Model

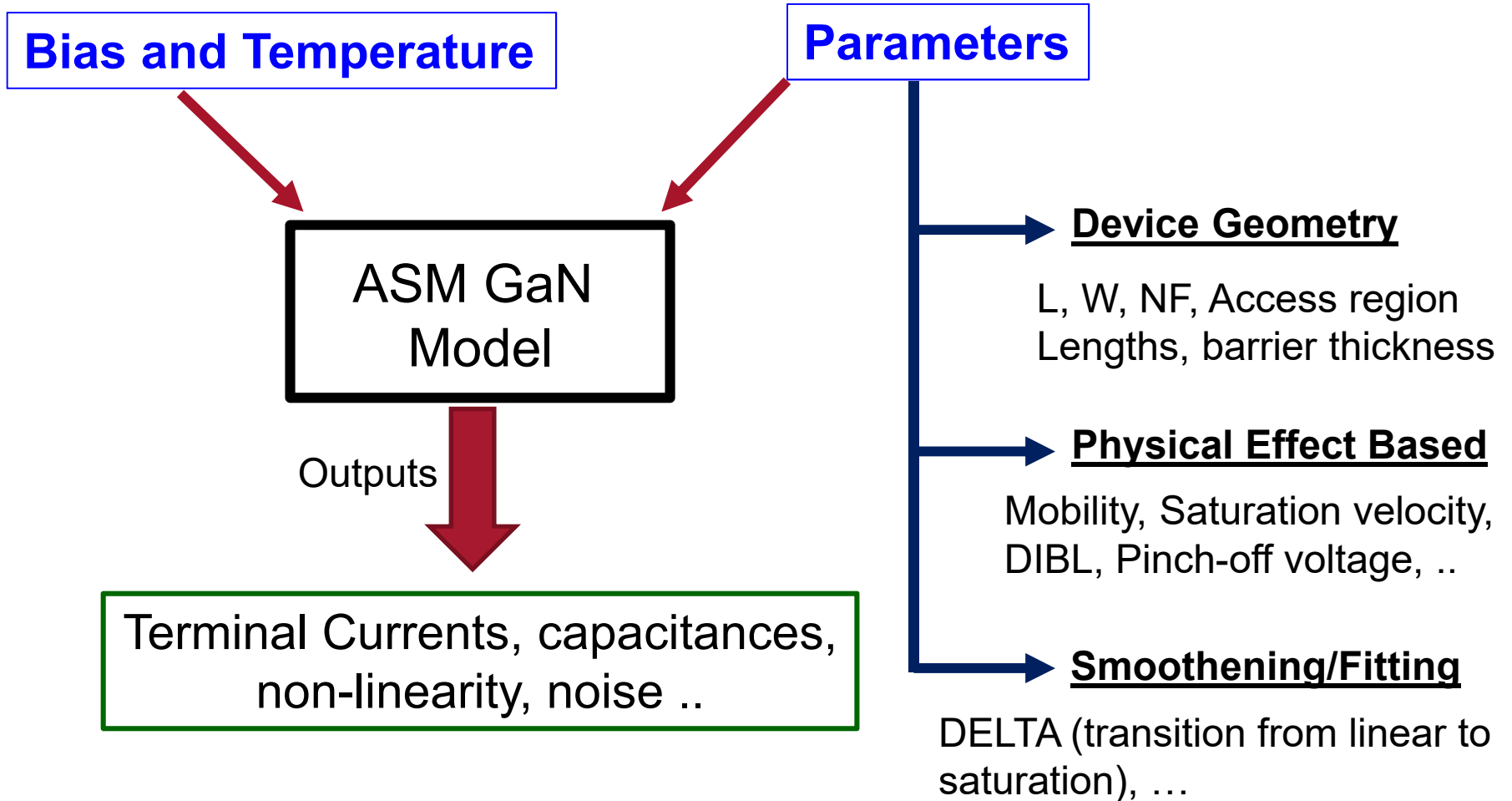
## INTRODUCTION

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- Recently selected as a **new industry standard model** by Compact Model Coalition (CMC)
- Selection through a multi-step process run by CMC over ~ 5.5 years
- Rigorously tested by CMC member companies
- Already available in several major commercial simulators
  - Available in ICCAP

# ASM GaN Model

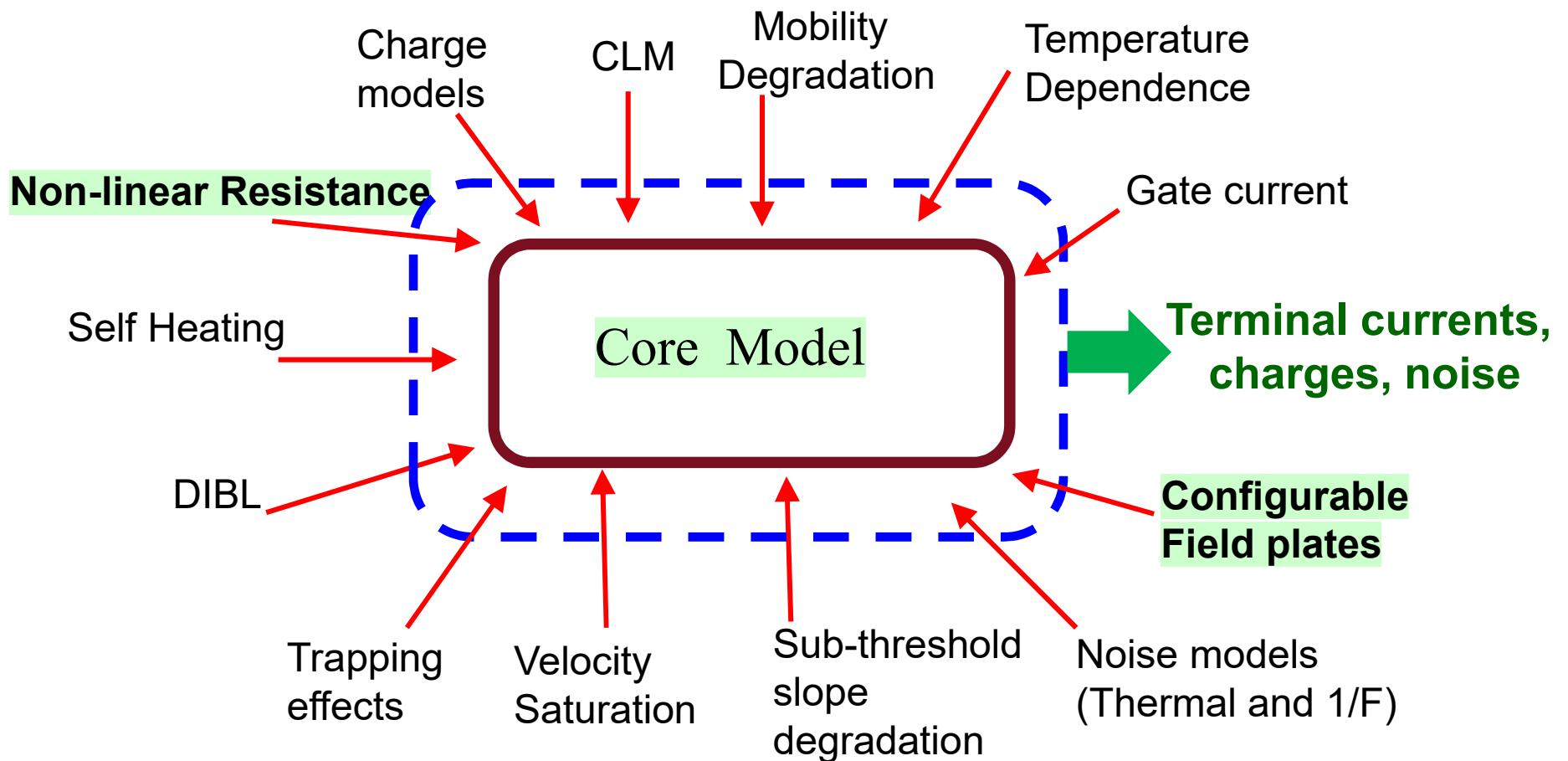
## INPUTS AND TYPES OF PARAMETERS



# ASM GaN Model

## CORE AND REAL DEVICE EFFECTS

**ASM GaN Model = Core model + Real device effect model**

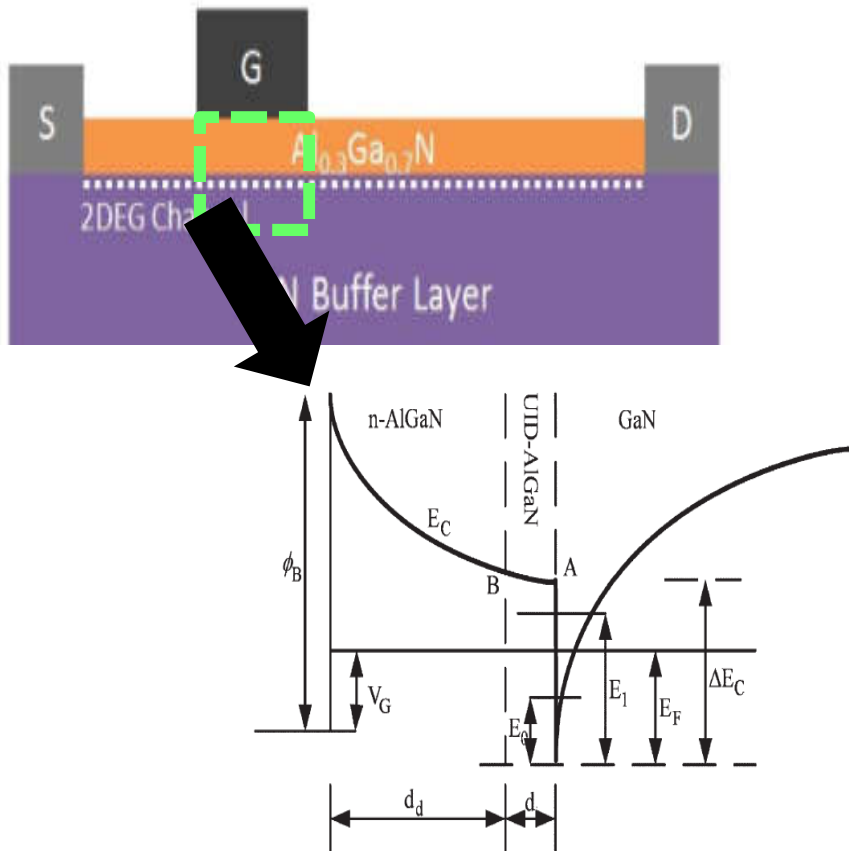




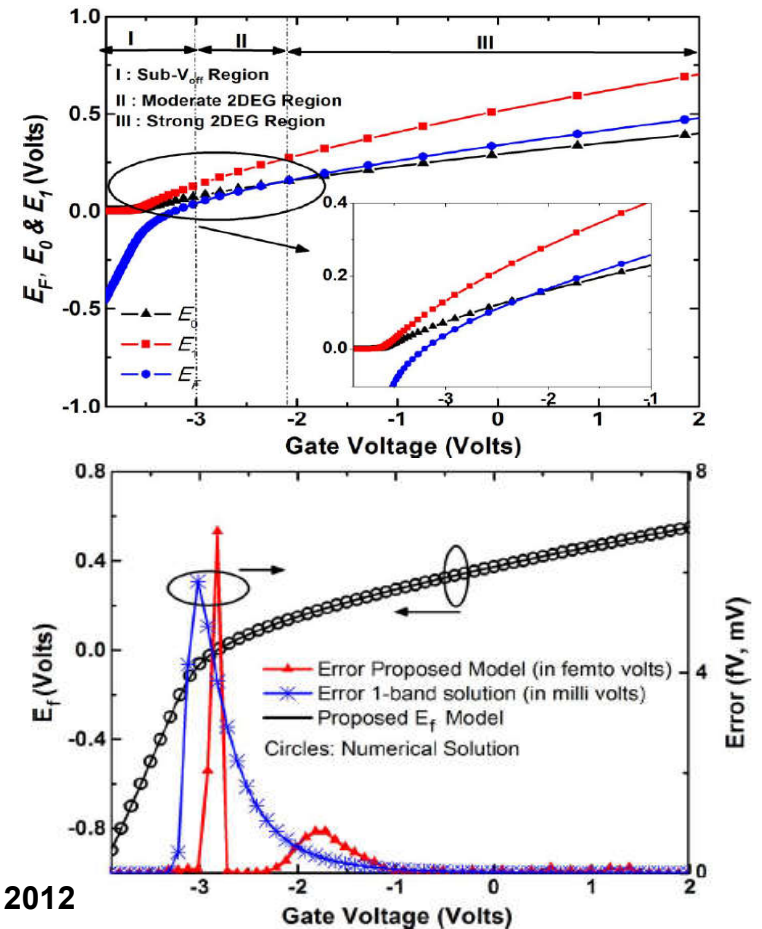
# ASM-GaN Core Model

## 2-DEG MODEL

- Analytical solution developed for convergence and speed

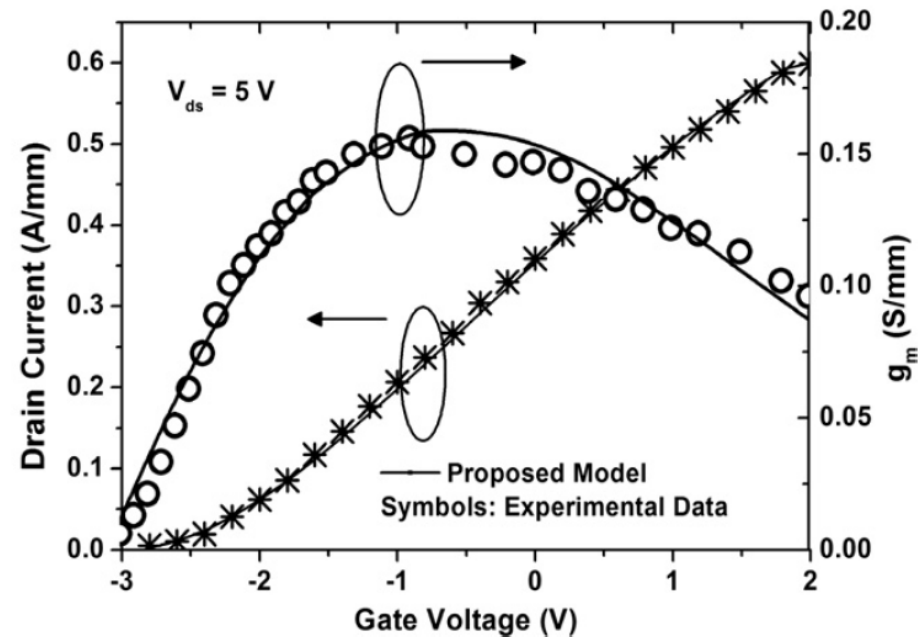
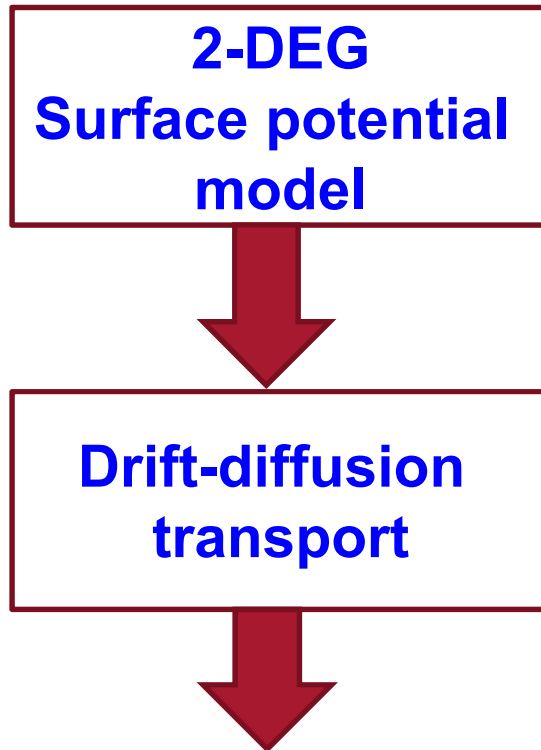


•S. Khandelwal et al. IEEE Trans. Elect. Dev. 2012



# ASM-GaN Model

## CORE CURRENT MODEL



$$I_{ds} = \frac{\mu_{eff} C_g}{\sqrt{1 + \theta_{sat}^2 \psi_{ds}^2}} \frac{W}{L} (V_{go} - \psi_m + V_{th}) (\psi_{ds}) (1 + \lambda V_{ds})$$

# ASM-GaN Model

## CORE CHARGE/CAPACITANCE MODEL

- Consistent model for terminal charges as function of surface-potential

$$Q_g = \int_0^L Wqn_s(V_g, V_x).dx$$

$$Q_d = -\int_0^L \frac{x}{L} Wqn_s(V_g, V_x).dx$$

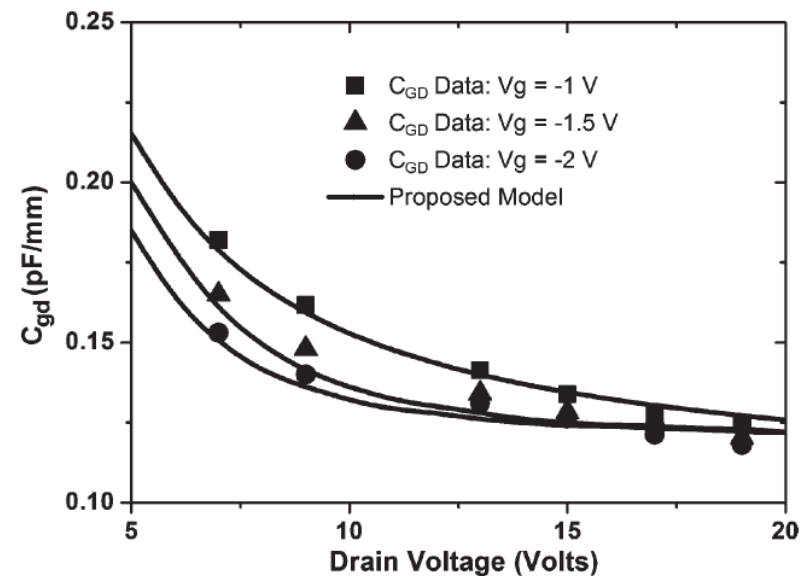
$$Q_s = -\int_0^L \left(1 - \frac{x}{L}\right) Wqn_s(V_g, V_x).dx$$

$$Q_g + Q_s + Q_d = 0$$

**Charge conservation for  
good convergence**

Dr Sourabh Khandelwal, Macquarie University

$$C_{ij} = -\frac{dQ_i}{dV_j}, C_{ii} = \frac{dQ_i}{dV_i}$$

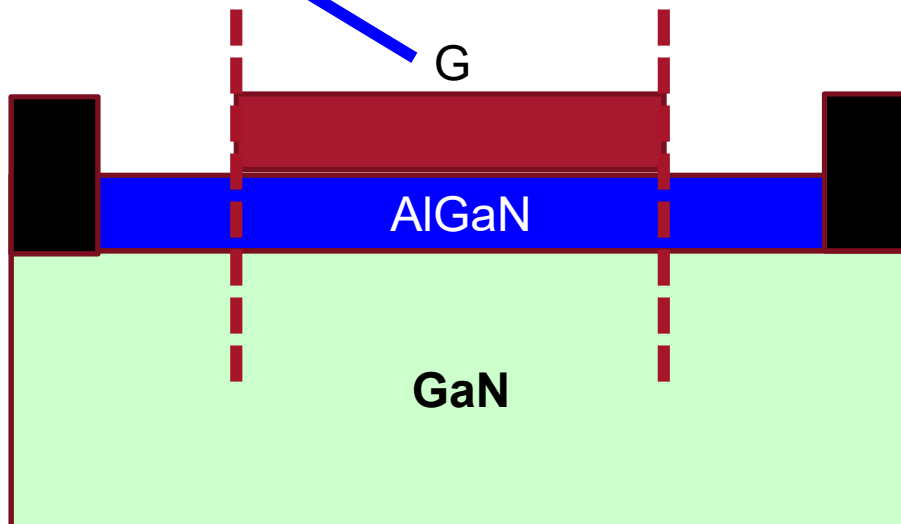


S. Khandelwal TED 2013

# ASM Core Model

## TERMINAL CHARGE MODEL

$$Q_g = \frac{C_g LW}{V_{g0} - \psi_m + V_{tv}} \left[ V_{g0}^2 + \frac{1}{3} (\psi_d^2 + \psi_s^2 + \psi_d \psi_s) - V_{g0} (\psi_d + \psi_s - V_{tv}) - V_{tv} \psi_m \right]$$

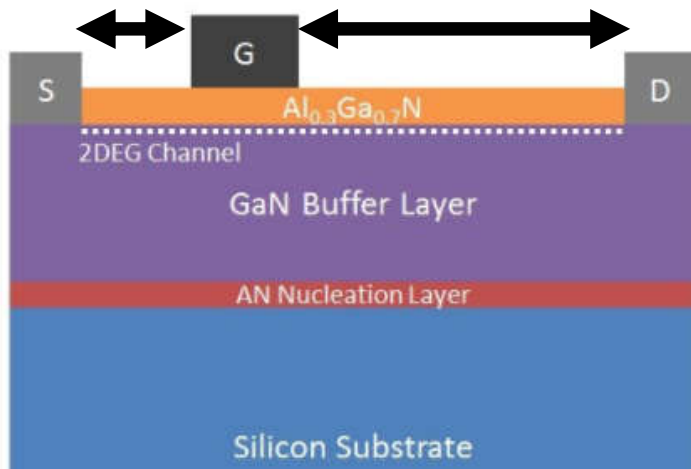


This equation accounts for gate-charge variation with applied  $V_G$ ,  $V_S$ , and  $V_D$ . It gives both CGS and CGD.

$$C_{ij} = -\frac{dQ_i}{dV_j}, C_{ii} = \frac{dQ_i}{dV_i}$$

# ASM GaN Model

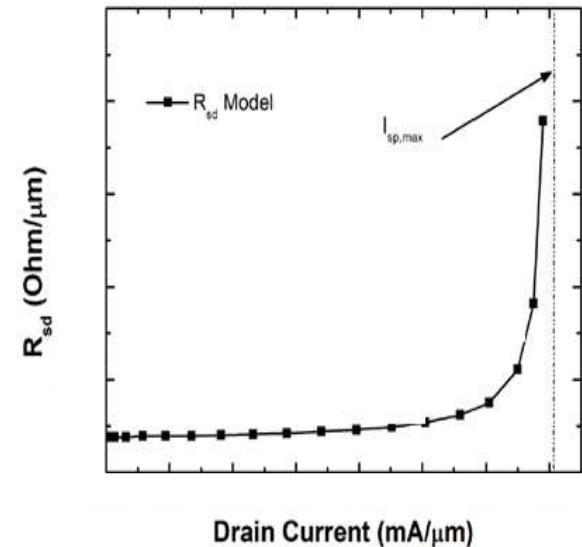
## MODELING NON-LINEAR ACCESS REGIONS



$$I_{sp} = \frac{V_{sp}}{R_{sp}} \begin{cases} \mu_0 \left( \frac{V_{sp}}{L_{sp}} \right) Q_{sp} & \text{Linear (Ohmic)} \\ v_{sat} Q_{sp} & \text{Saturation} \end{cases}$$

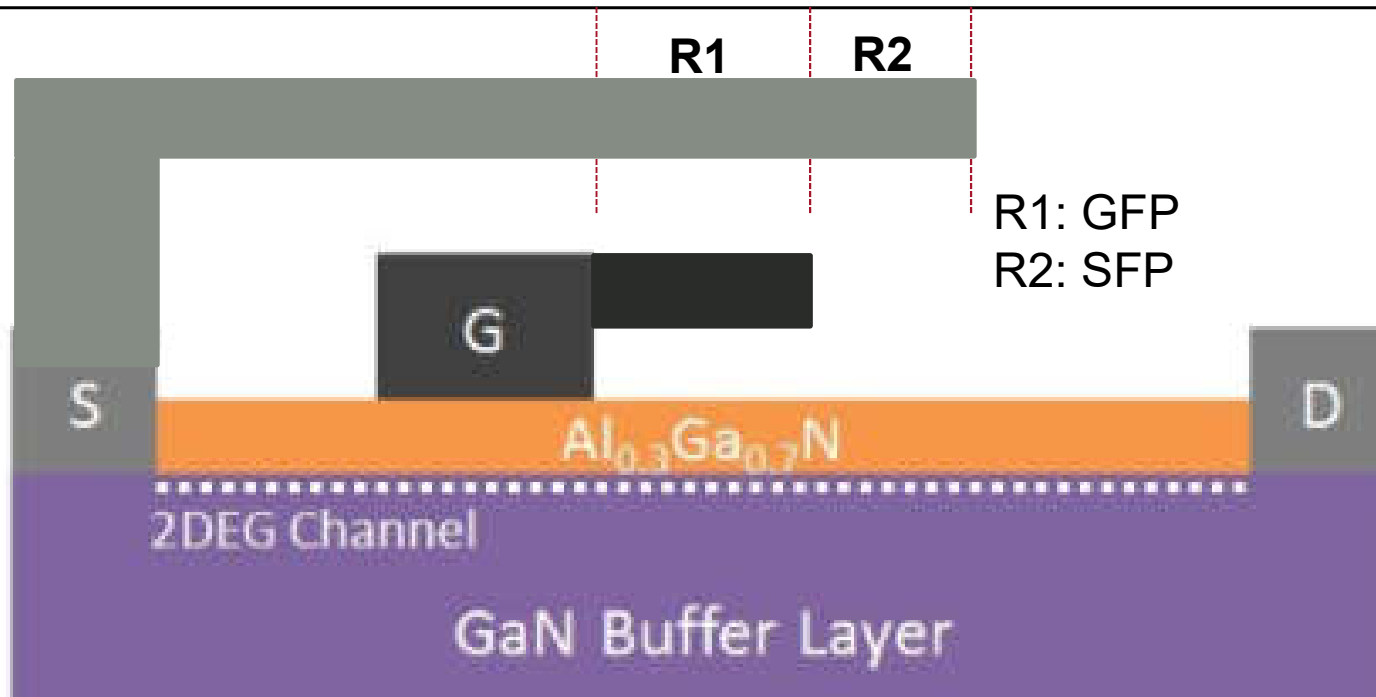
$$I_{sp} = \frac{Q_{sp} v_{sat} V_{sp}}{\left( V_{sp,sat}^\beta + V_{sp}^\beta \right)^{1/\beta}} \quad V_{sp,sat} = L_{sp} v_{sat} / \mu_0$$

$$R_{sd} = \frac{R_{sh}}{\left( 1 - \left( \frac{I_d}{I_{sp,max}} \right)^\beta \right)^{1/\beta}}$$



# ASM GaN Model

## CONFIGURABLE FIELD PLATE MODEL

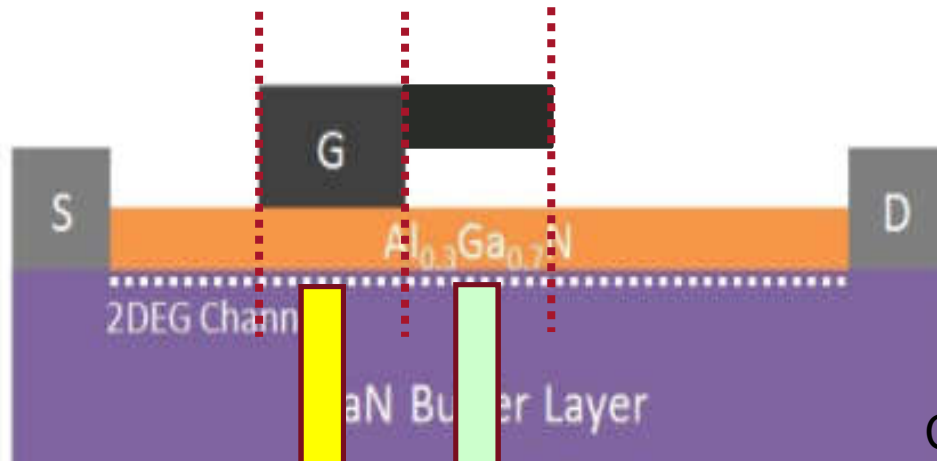


- ASM model allows configurable field-plate option through model switch FPMOD
- Users can set different regions of device to be GFP/SFP/DFP
- Four configurable field plates supported in the model

# ASM GaN Model

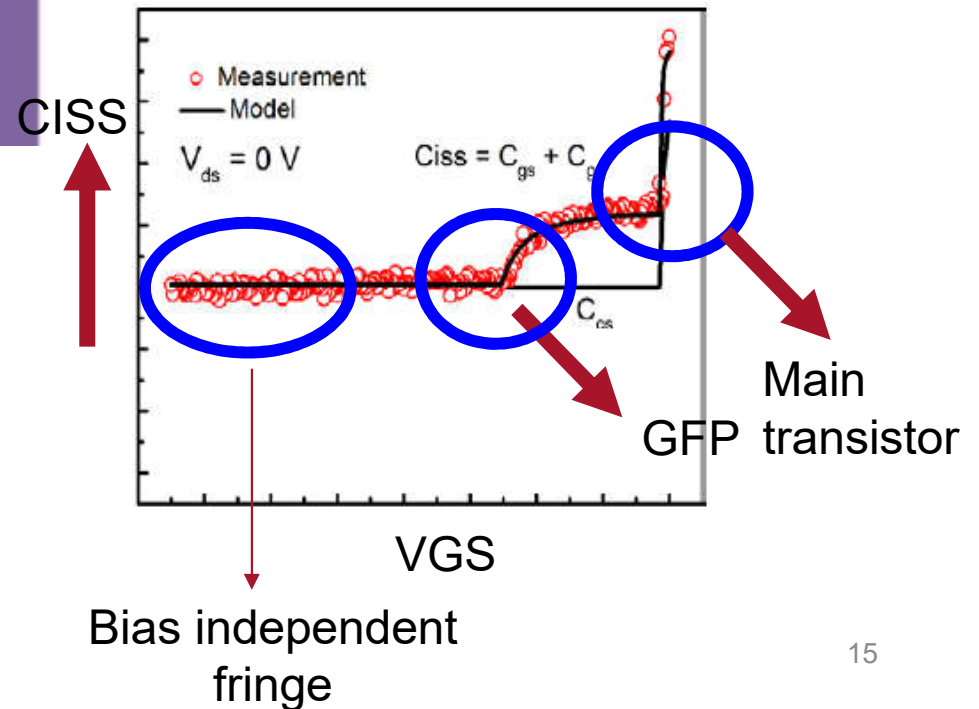
## FIELD-PLATE MODELING

CISS Versus VGS (measured for VDS=0) for device with GFP



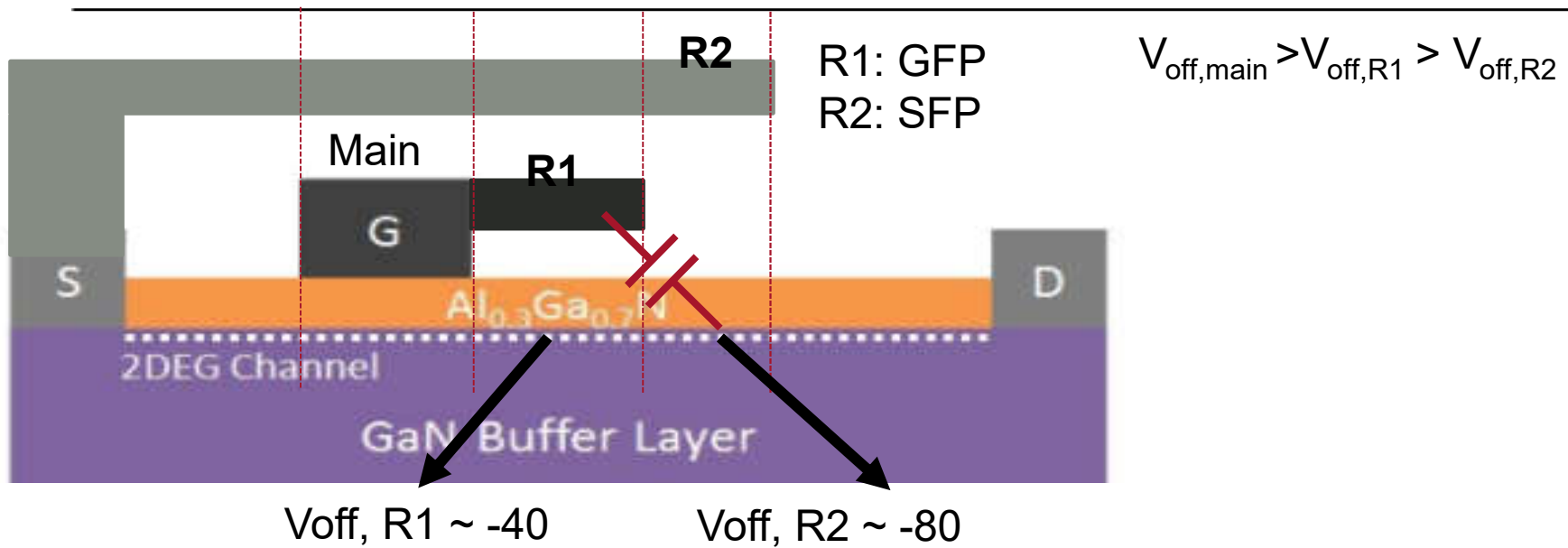
QGint QGFP1

$$QG = QGint + QGFP1$$



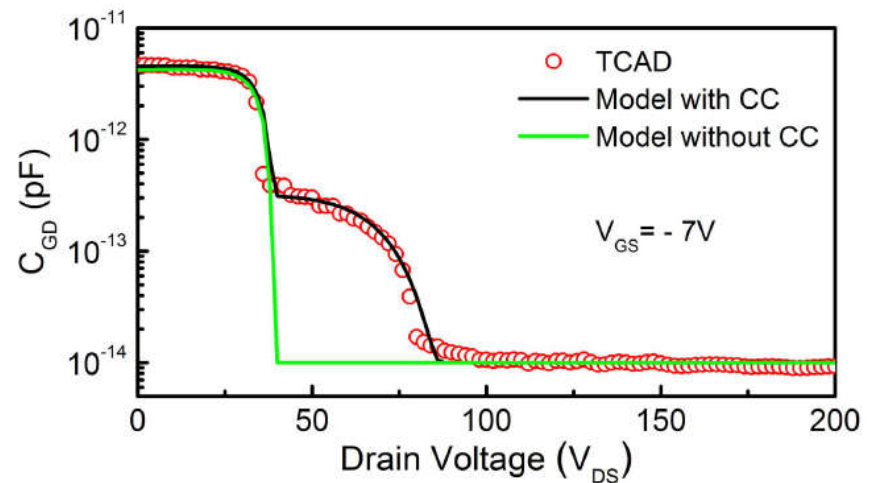
# ASM GaN Model

## FIELD PLATE MODEL: COUPLING EFFECT



**Coupling from SFP region to Gate**

**Important to model for accurate CGD**

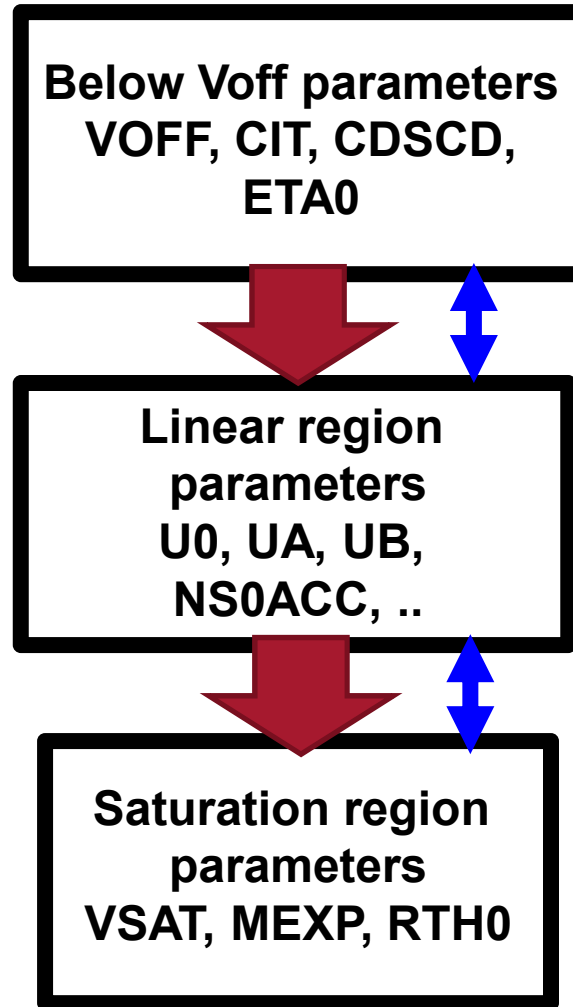




# ASM GaN Model

## DC EXTRACTION FLOW

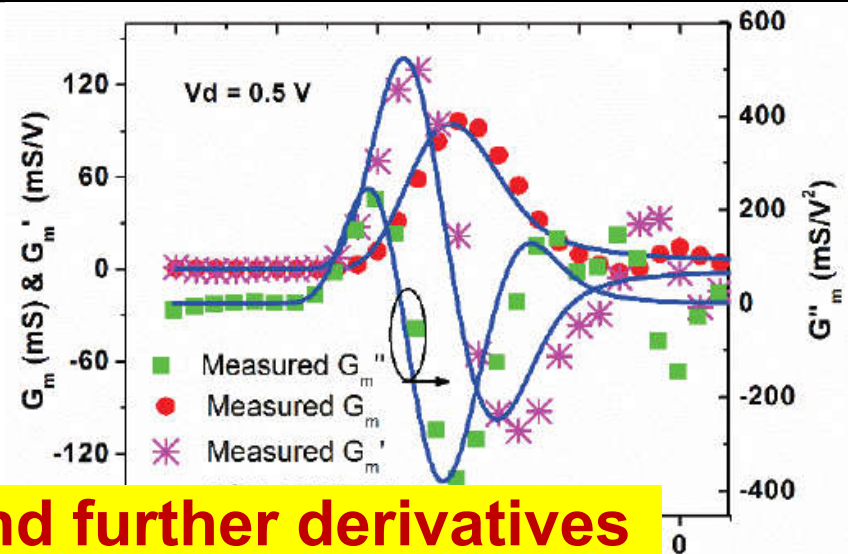
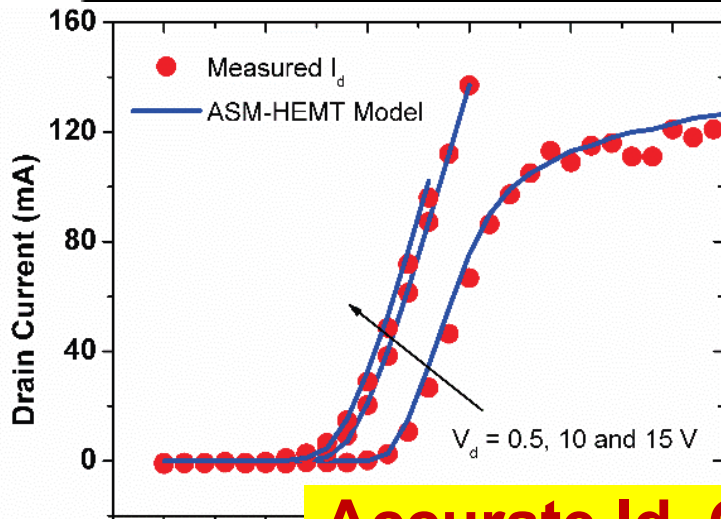
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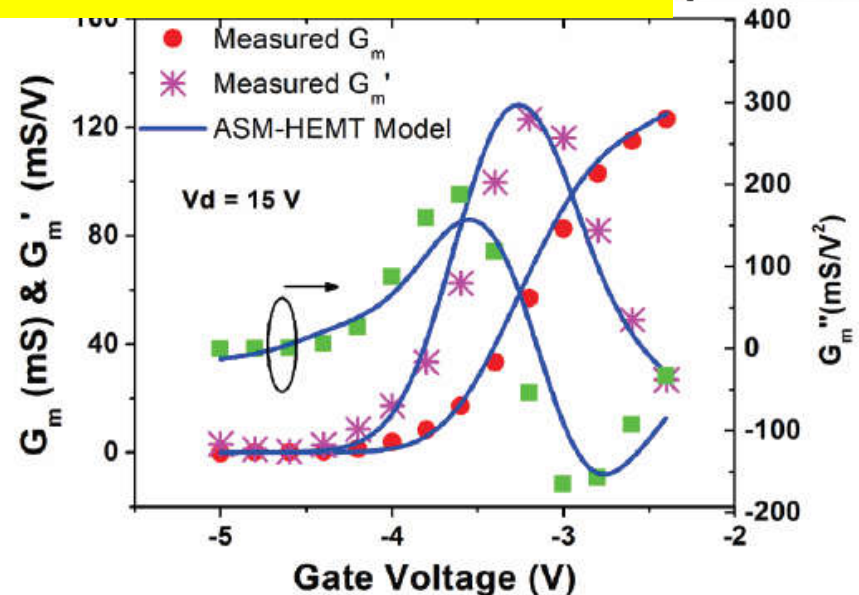
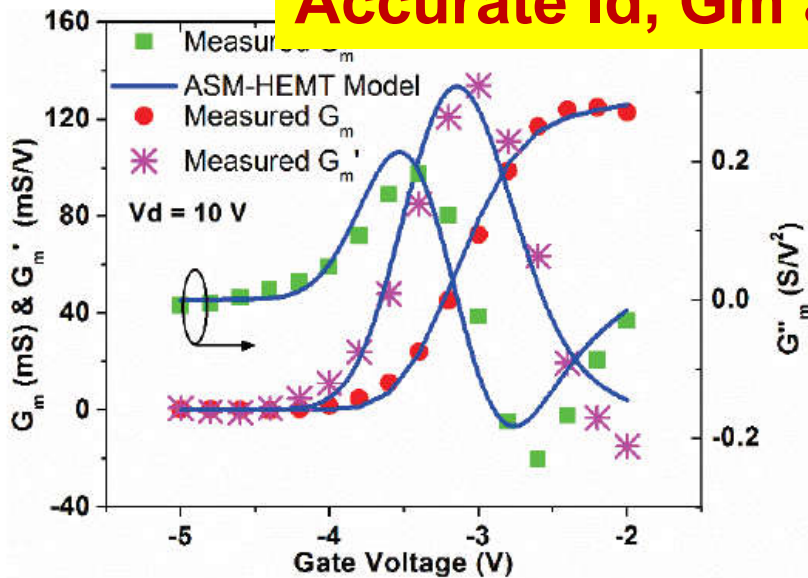
IDVG, IDVD  
GMVG, GDVD  
and higher order  
derivatives of  
I-V should be fitted

# ASM GaN Model

## RF DEVICE RESULTS: DC I-V MODEL



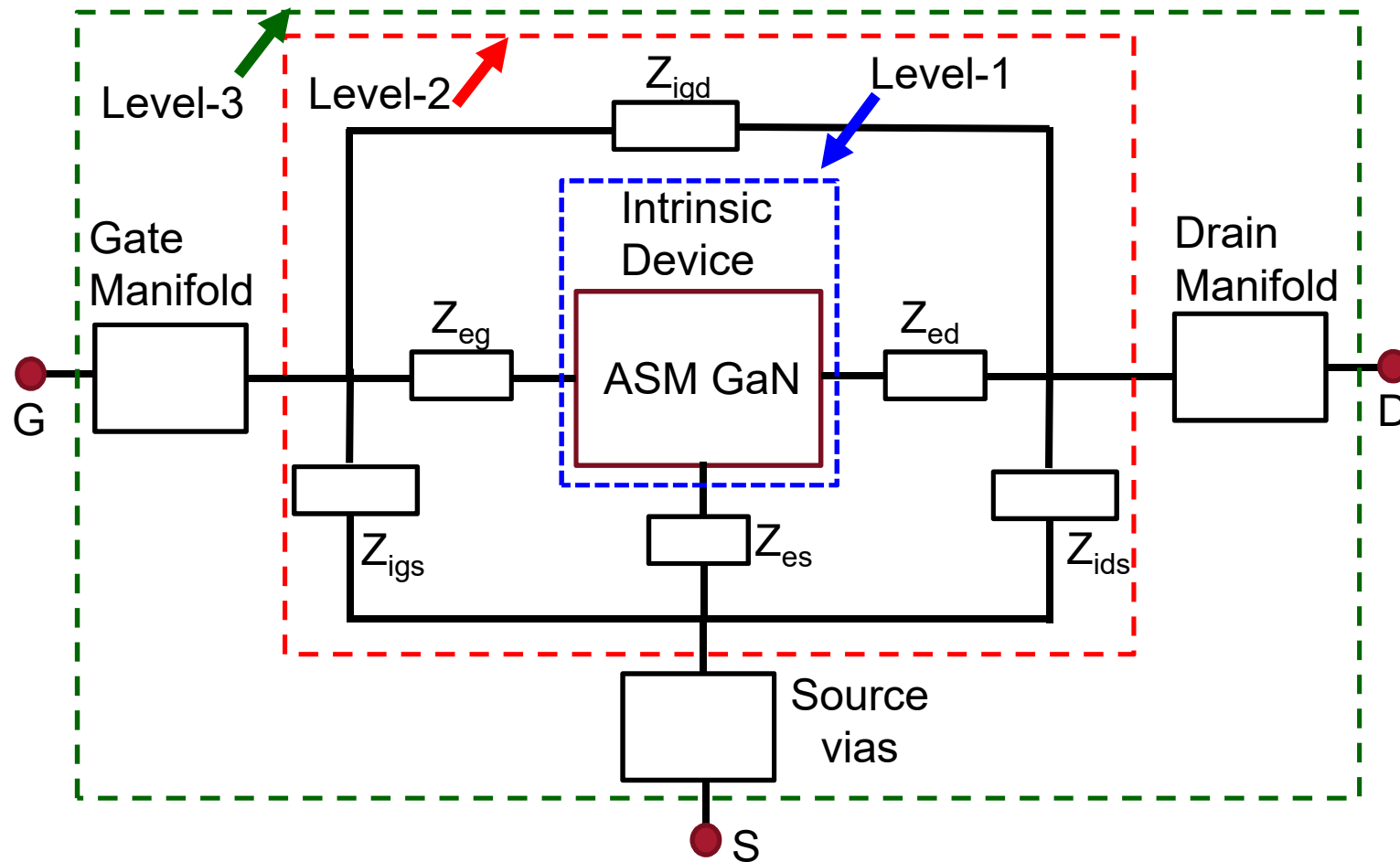
**Accurate  $I_d$ ,  $G_m$  and further derivatives**



# ASM GaN Model RF Device Results

# ASM GaN Model

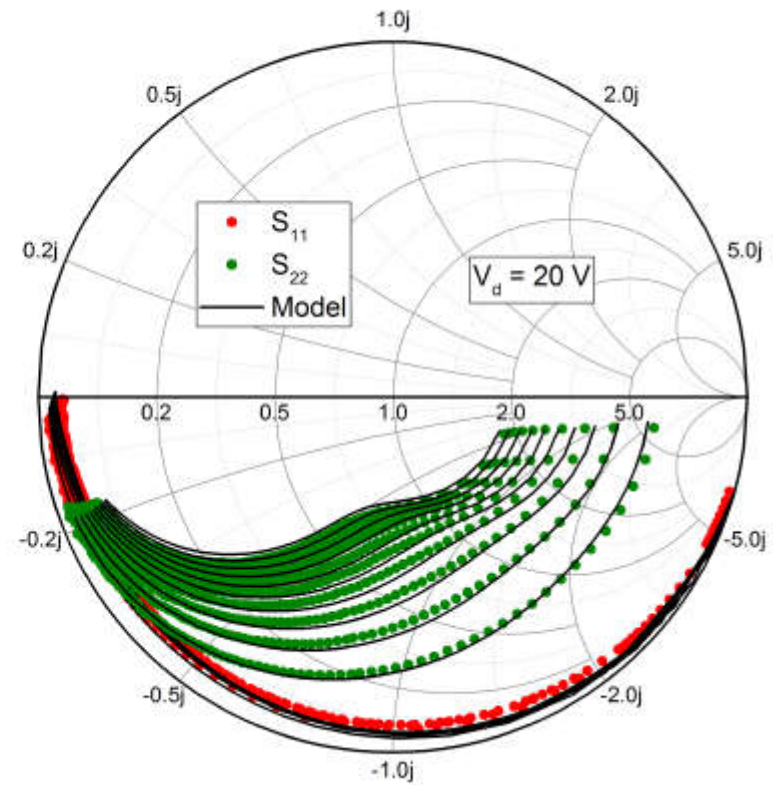
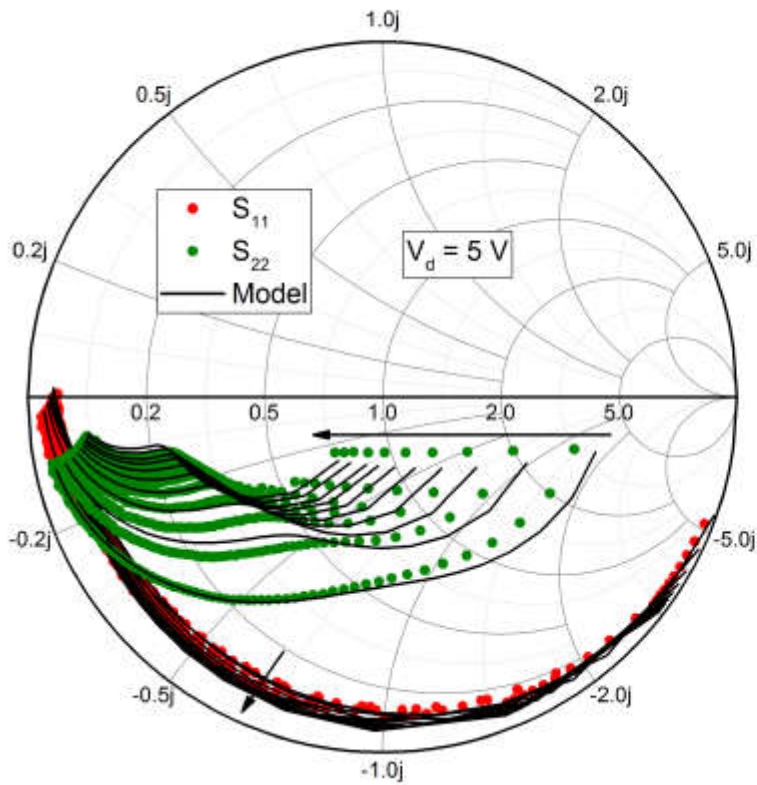
## COMPLETE RF MODEL



# ASM GaN Model

## RF DEVICE RESULTS: S PARAMETERS

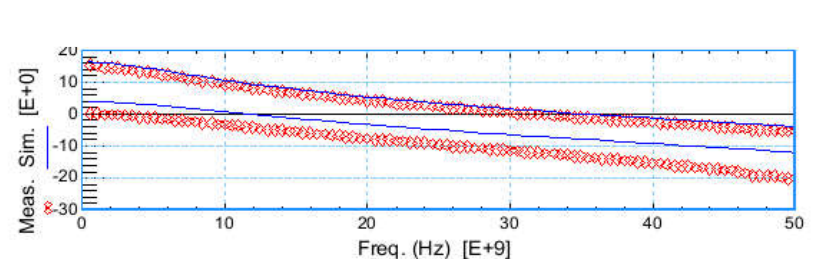
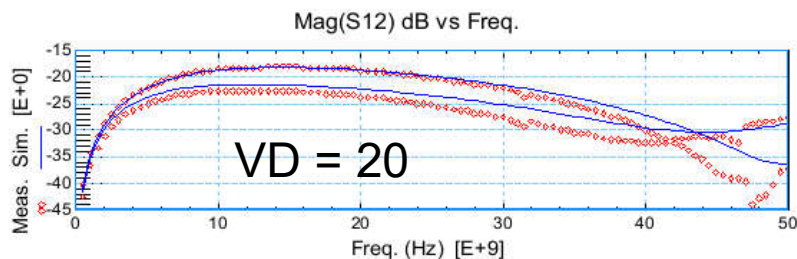
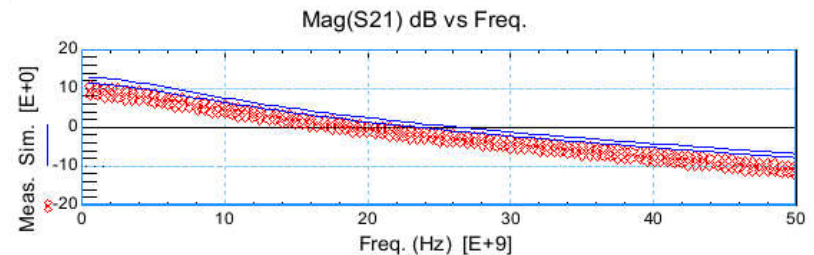
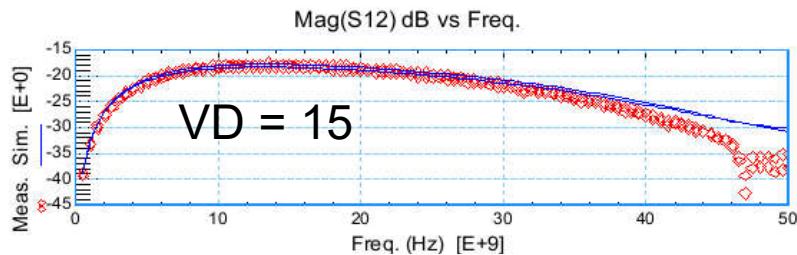
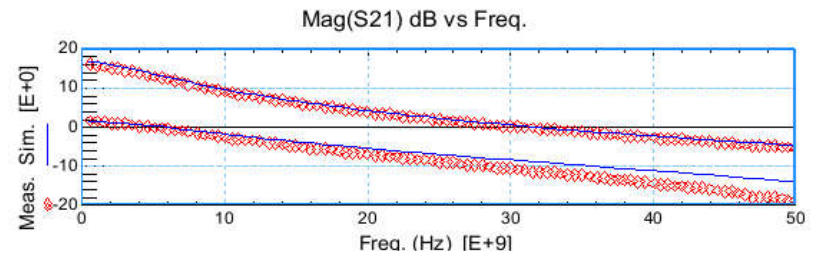
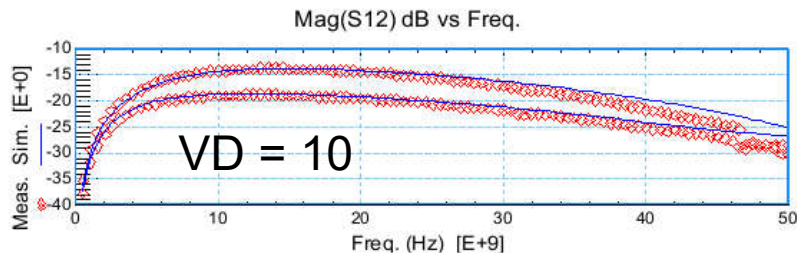
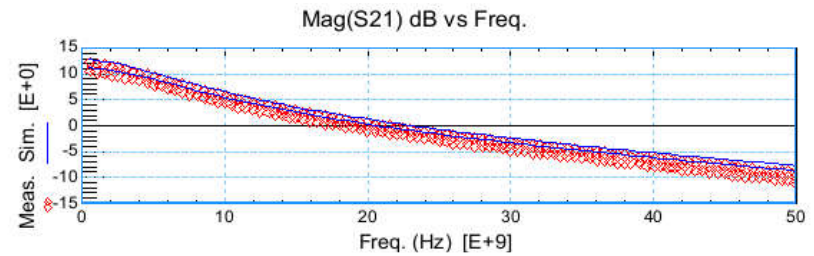
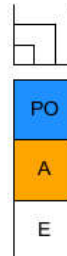
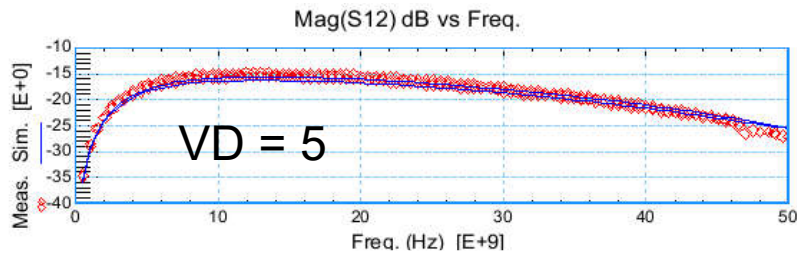
### Multi-bias S11 and S22 from 0.5 GHz to 50 GHz



# ASM GaN Model

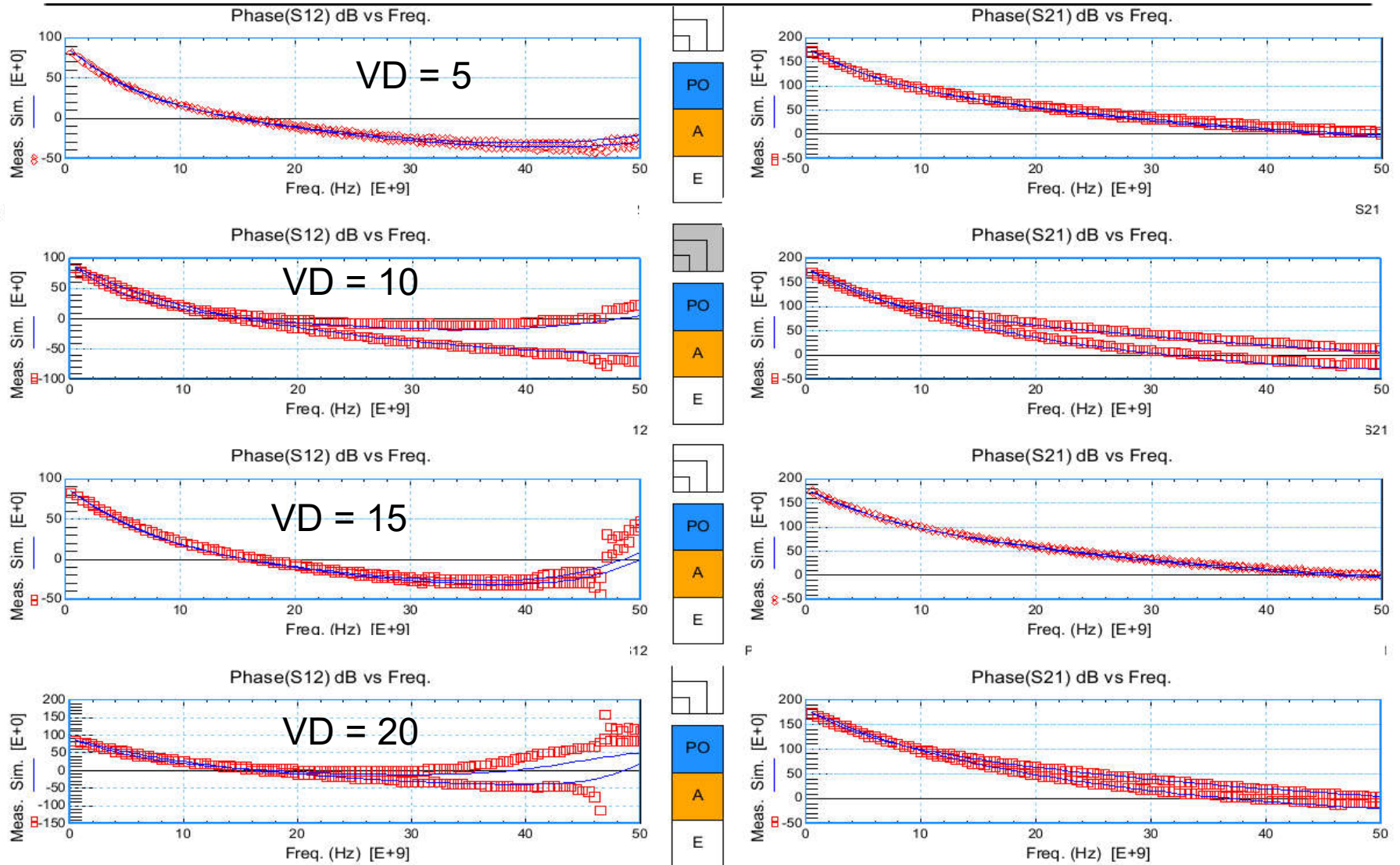


## RF DEVICE RESULTS: S PARAMETERS



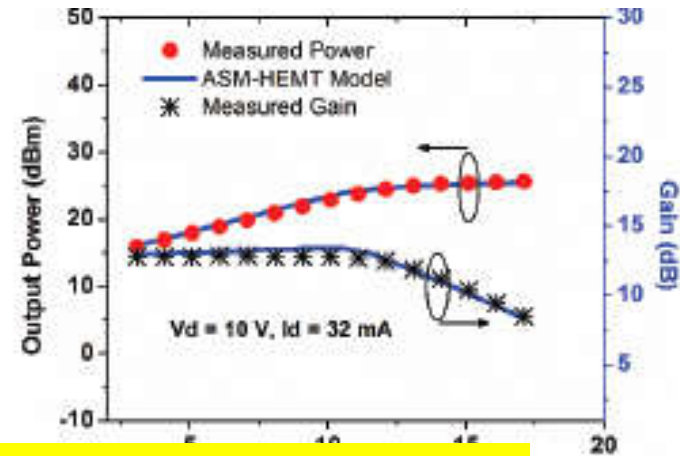
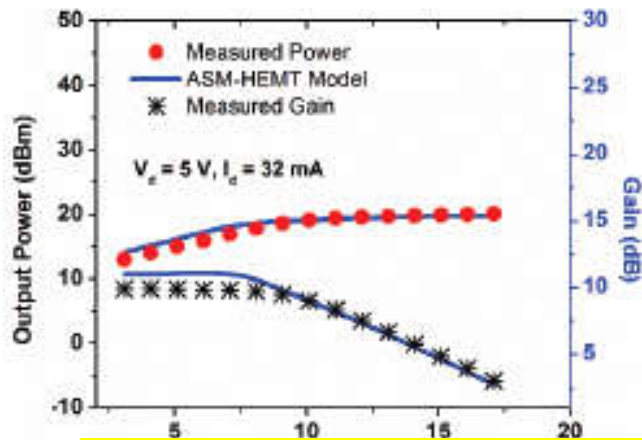
# ASM GaN Model

## RF DEVICE RESULTS: S PARAMETERS

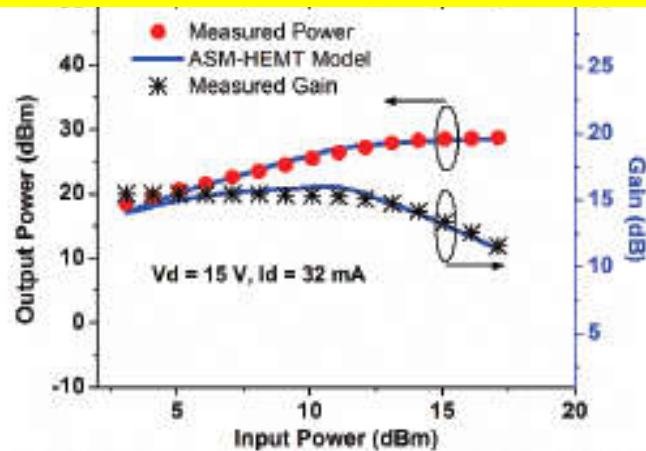


# ASM GaN Model

## LARGE SIGNAL RF RESULTS



**Accurate multi-bias large-signal results**

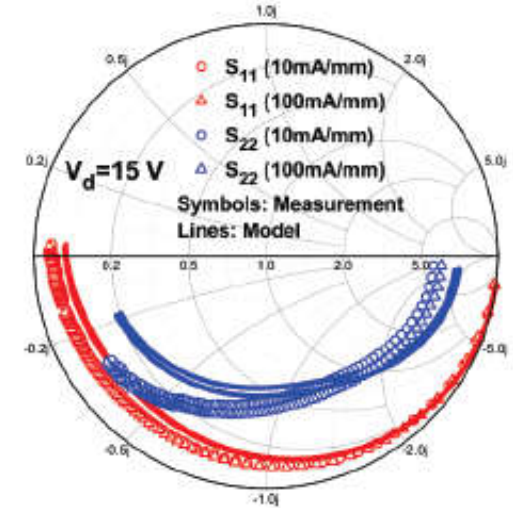
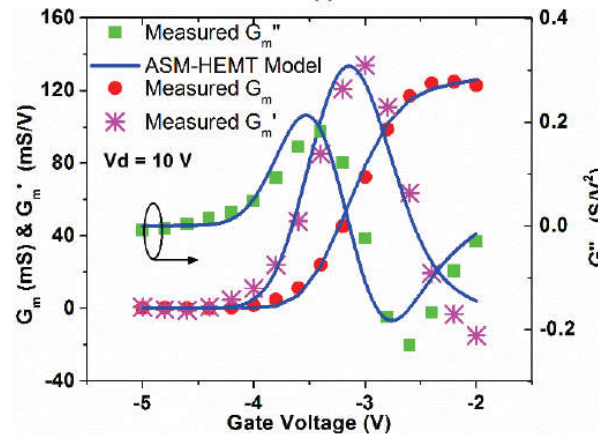
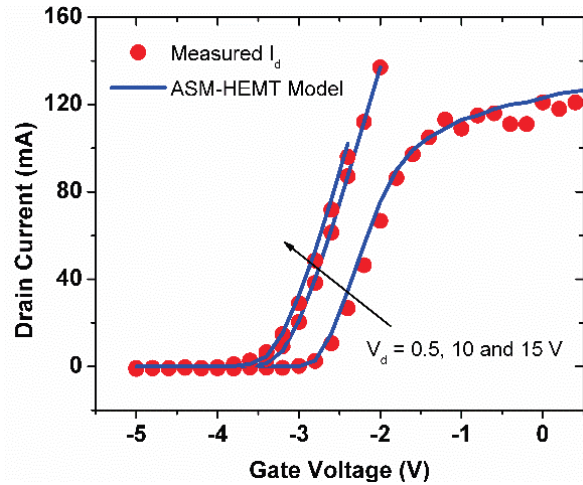


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CSICS 2015

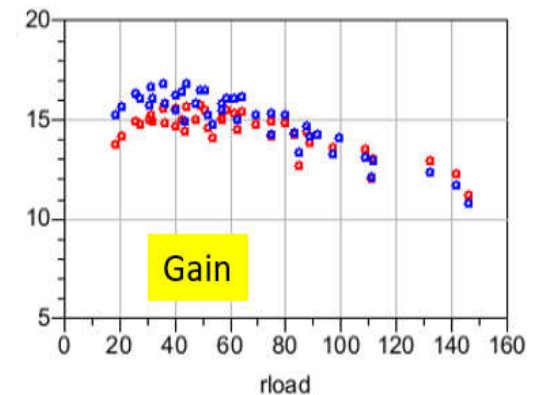
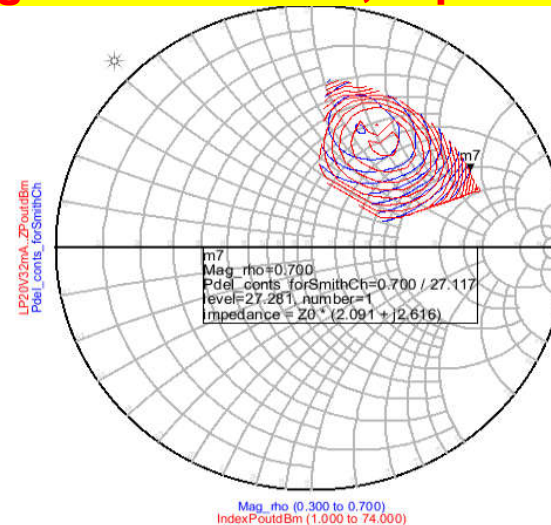
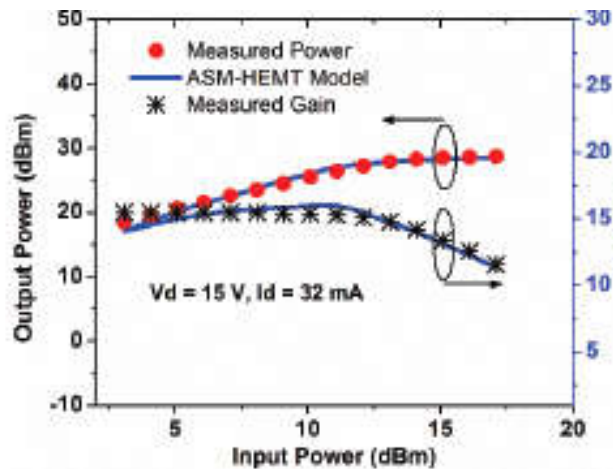


# ASM GaN Model

## RADIO FREQUENCY RESULTS SUMMARY



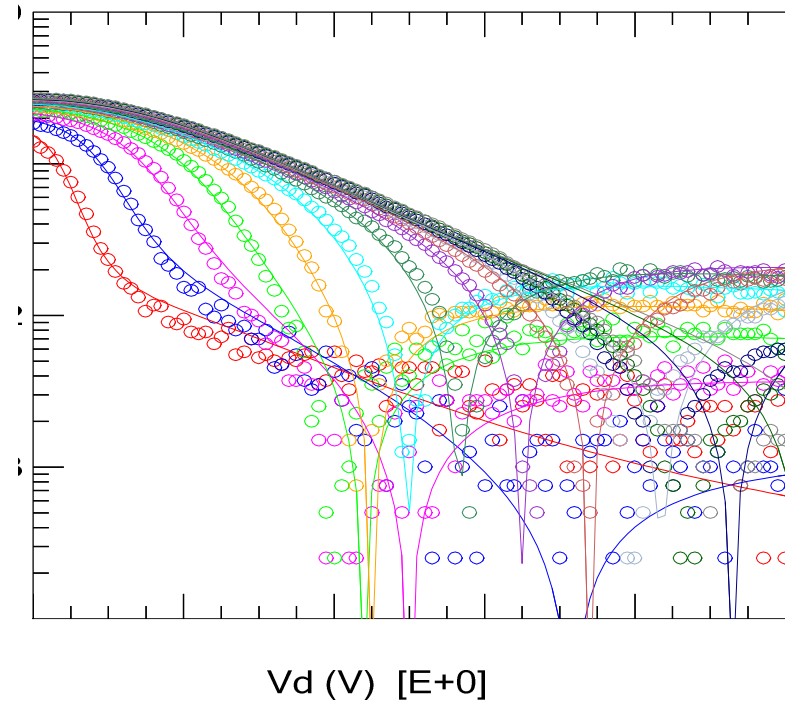
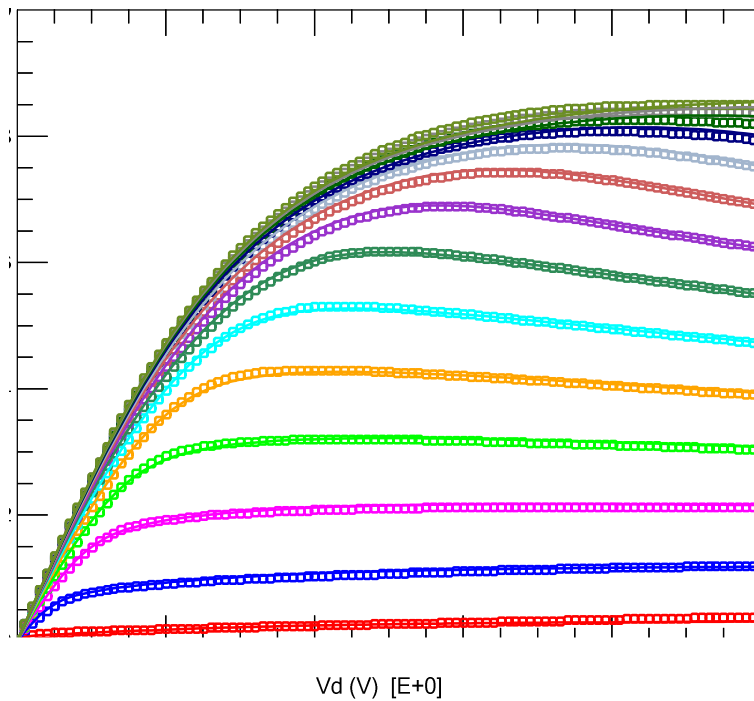
**Accurate DC, higher derivatives, S param, Load-pull**



# ASM GaN Model Power Device Results

# ASM GaN Model

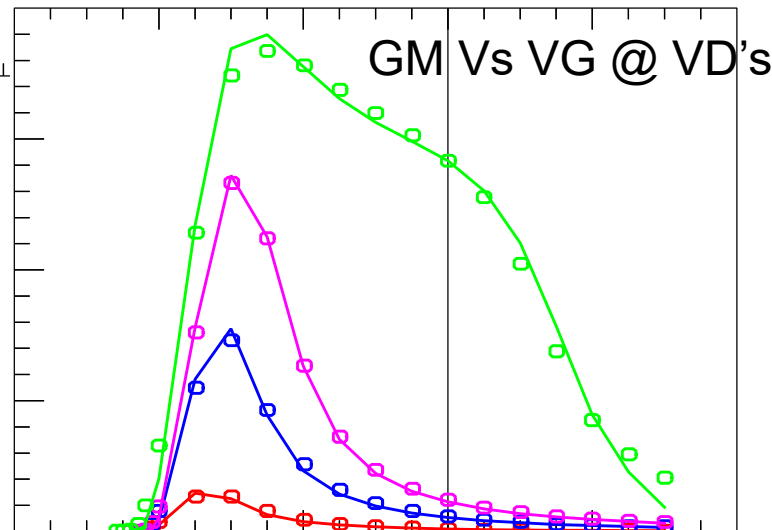
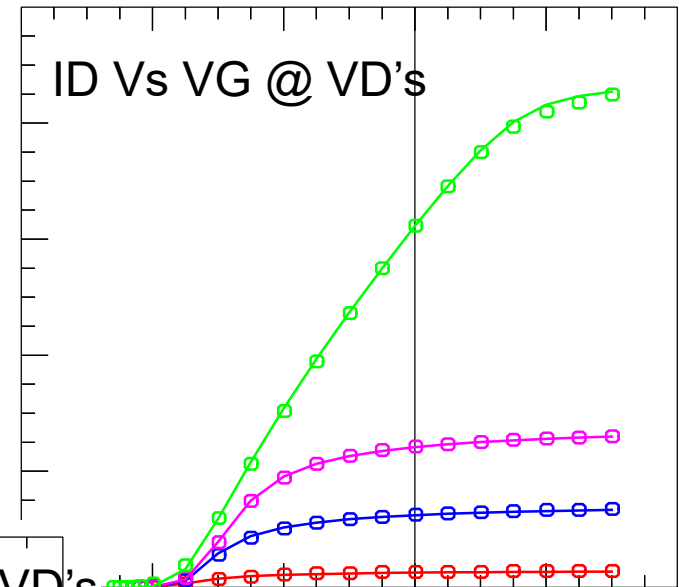
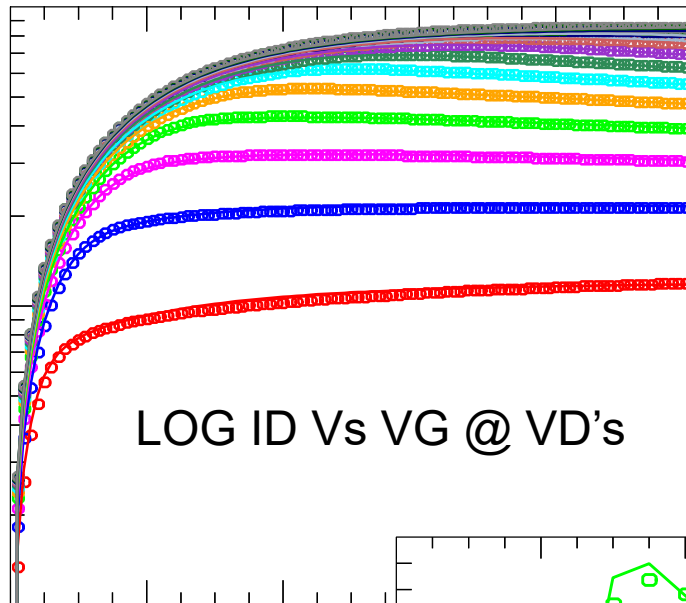
## POWER DEVICE I-V MODEL



**Accurate IV results**

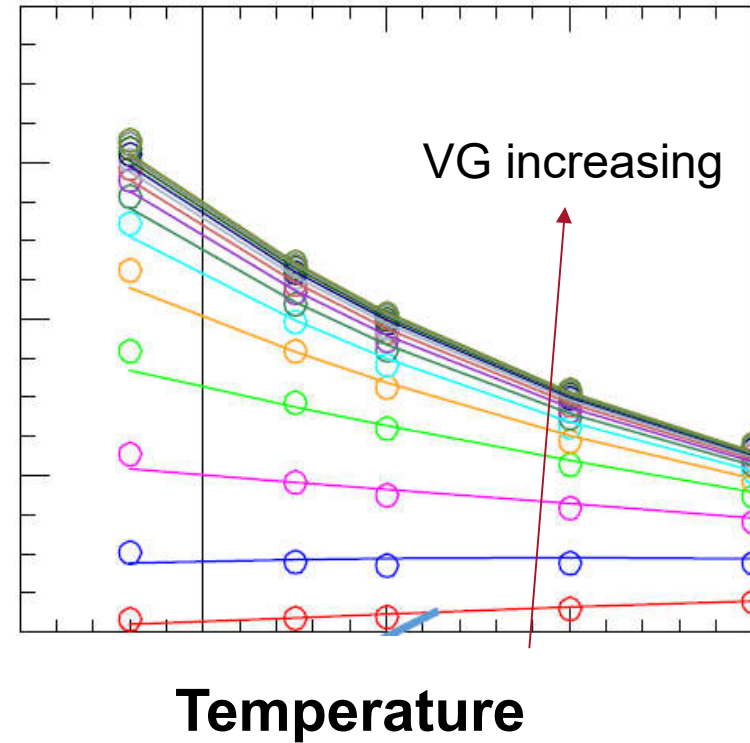
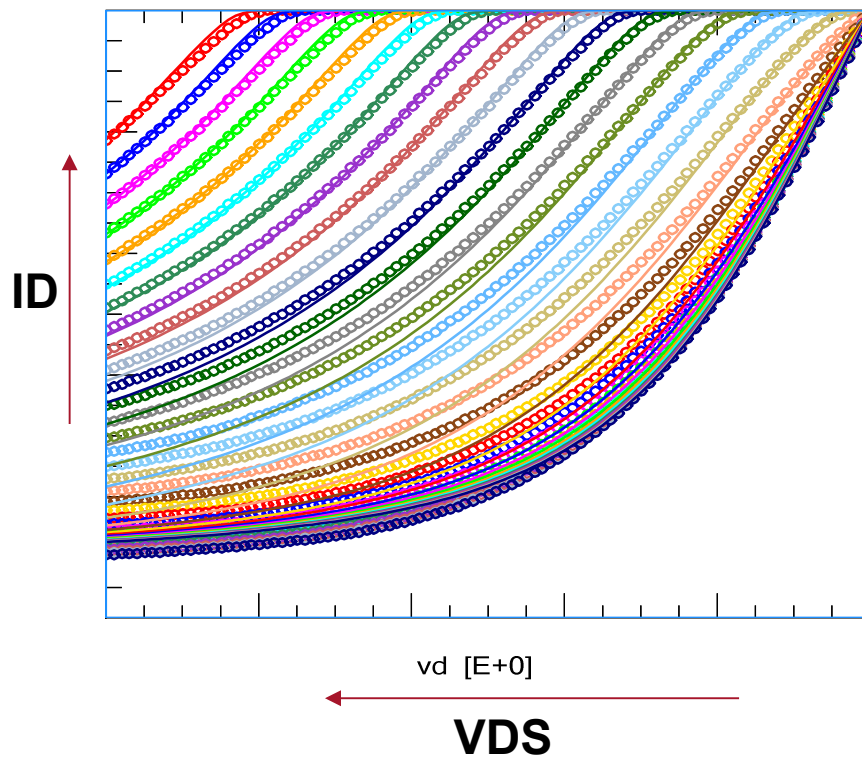
# ASM GaN Model

## POWER DEVICE I-V MODEL



# ASM GaN Model

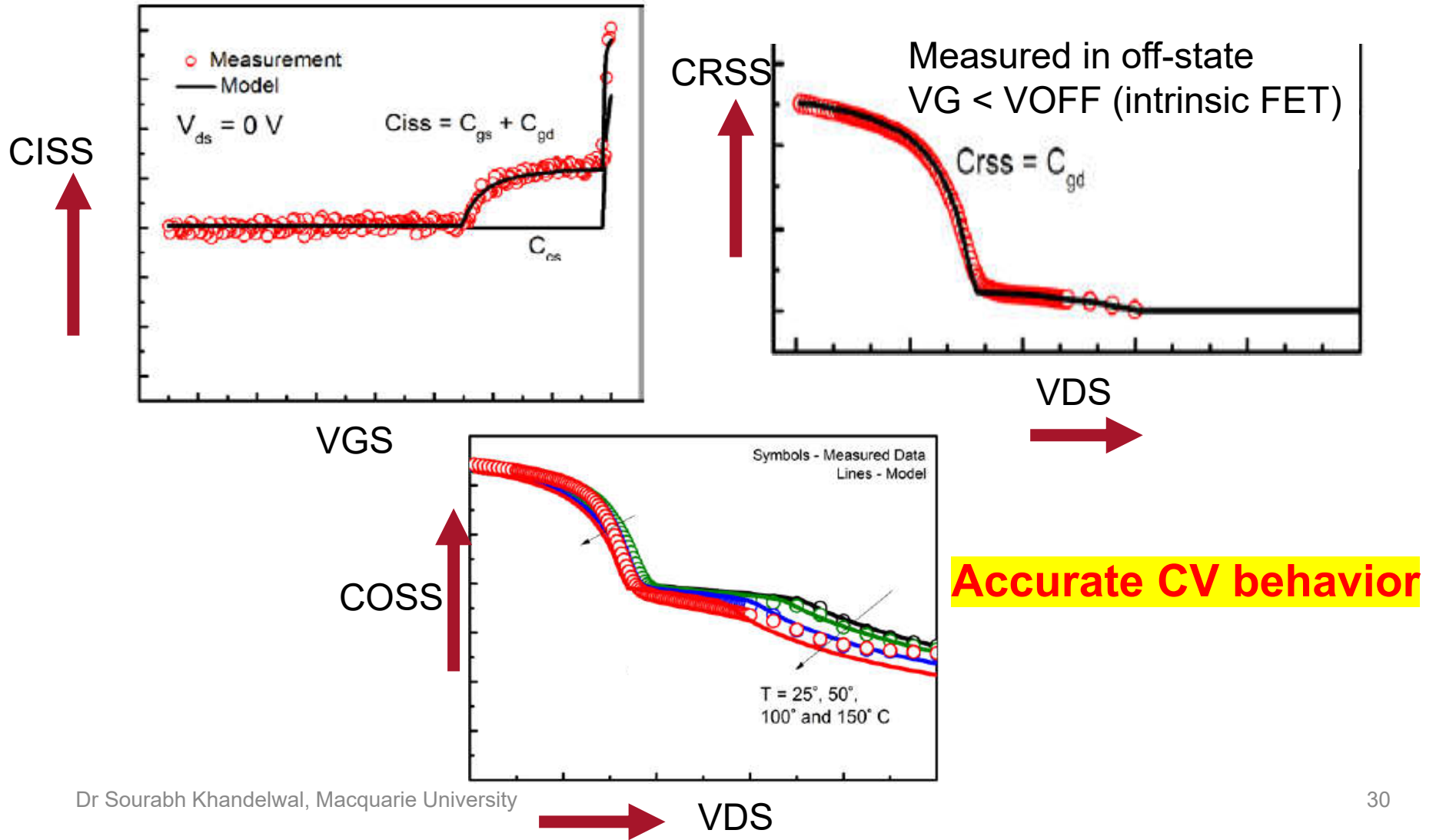
## REVERSE CONDUCTION AND TEMPERATURE SCALING



**Accurate reverse IV (3<sup>rd</sup> quadrant) and temperature results**

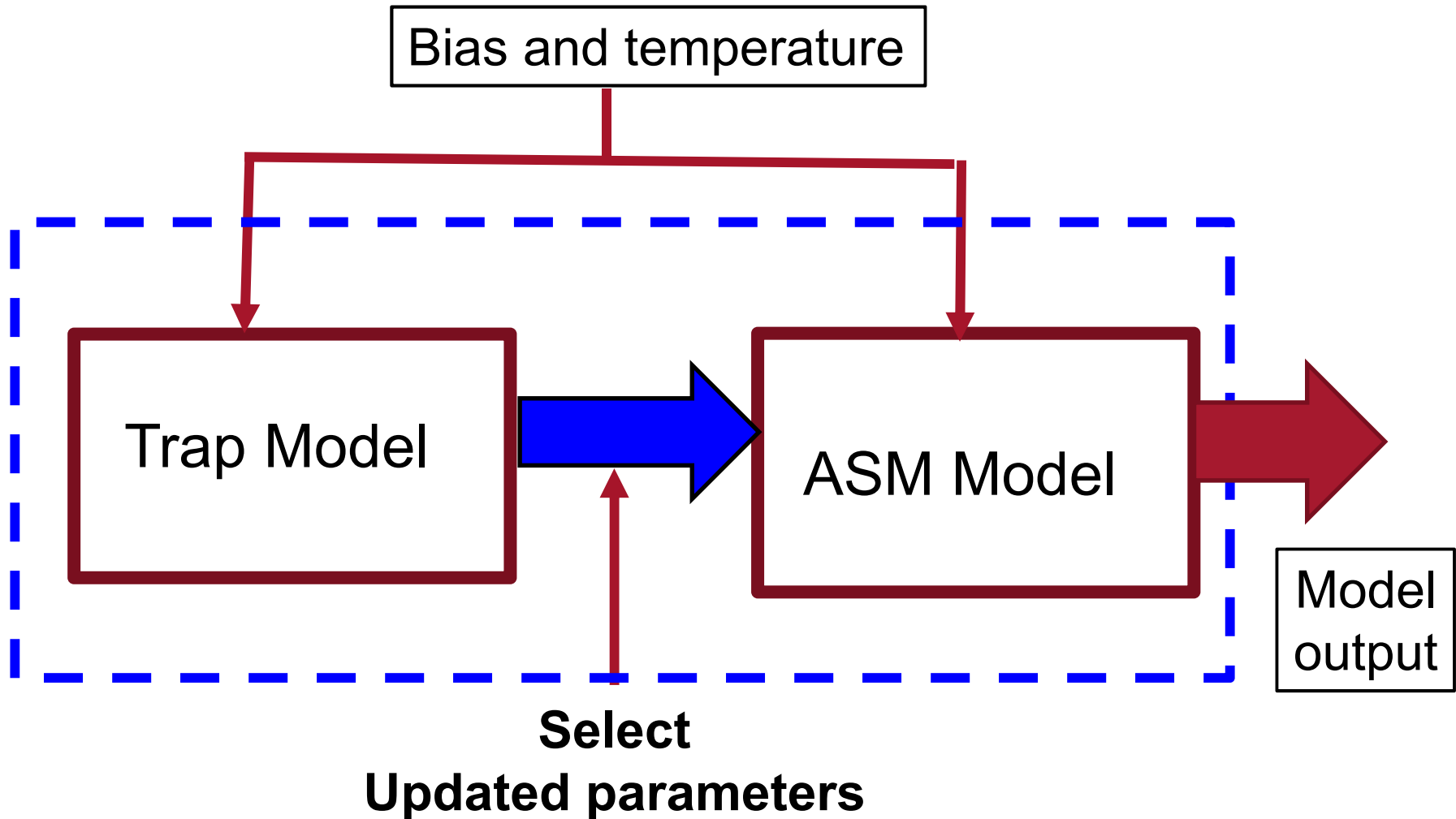
# ASM GaN Model

## CAPACITANCE MODEL



# ASM GaN Model

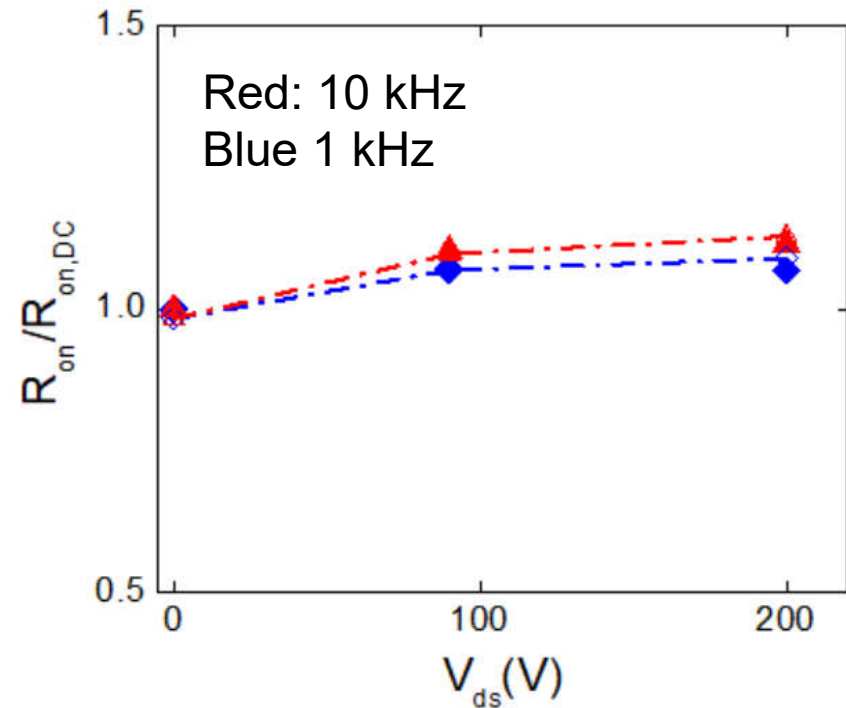
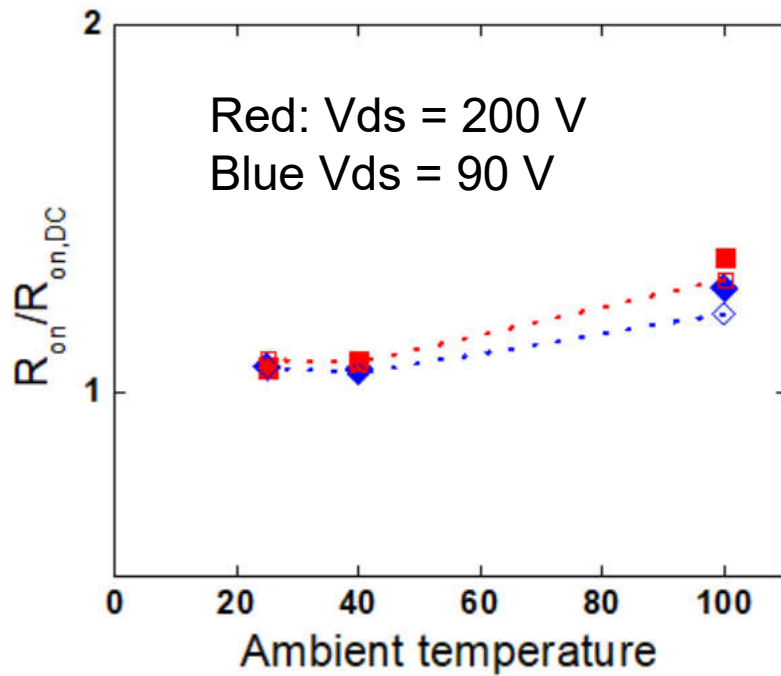
TRAPPING EFFECTS/DYNAMIC ON RESISTANCE



# ASM GaN Model

## DYNAMIC ON RESISTANCE MODEL

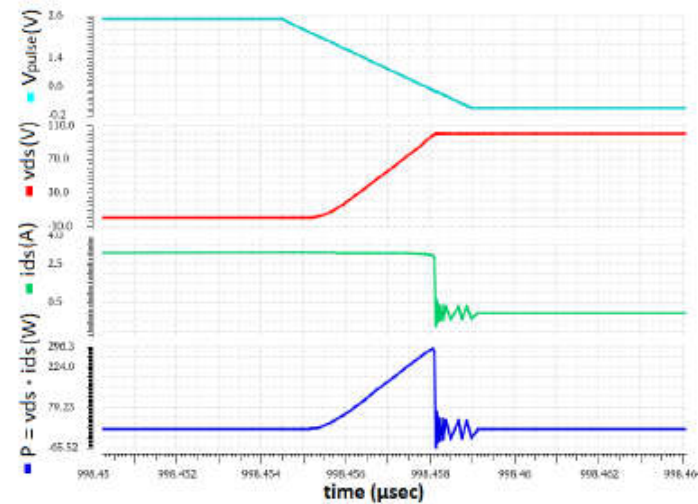
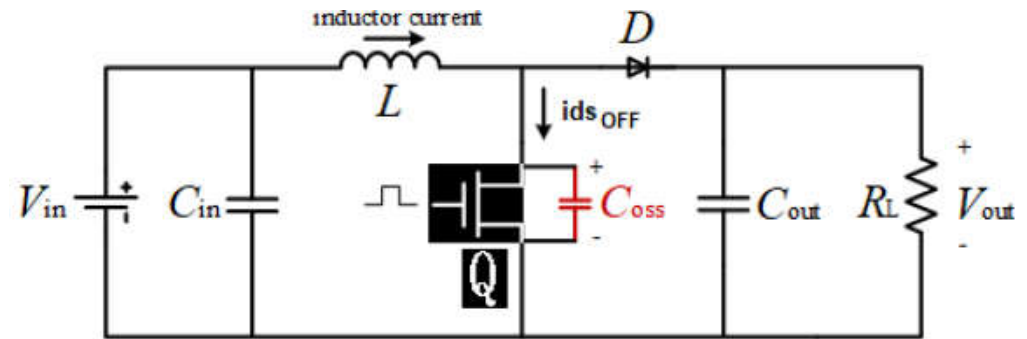
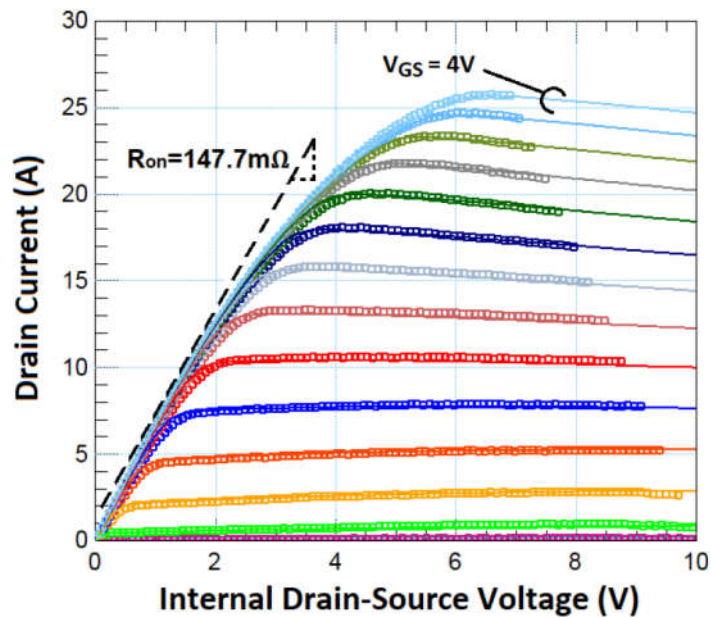
Dynamic on-resistance model: frequency, voltage and temperature dependence





# ASM GaN Model

## COMMERCIAL POWER DEVICE MODEL

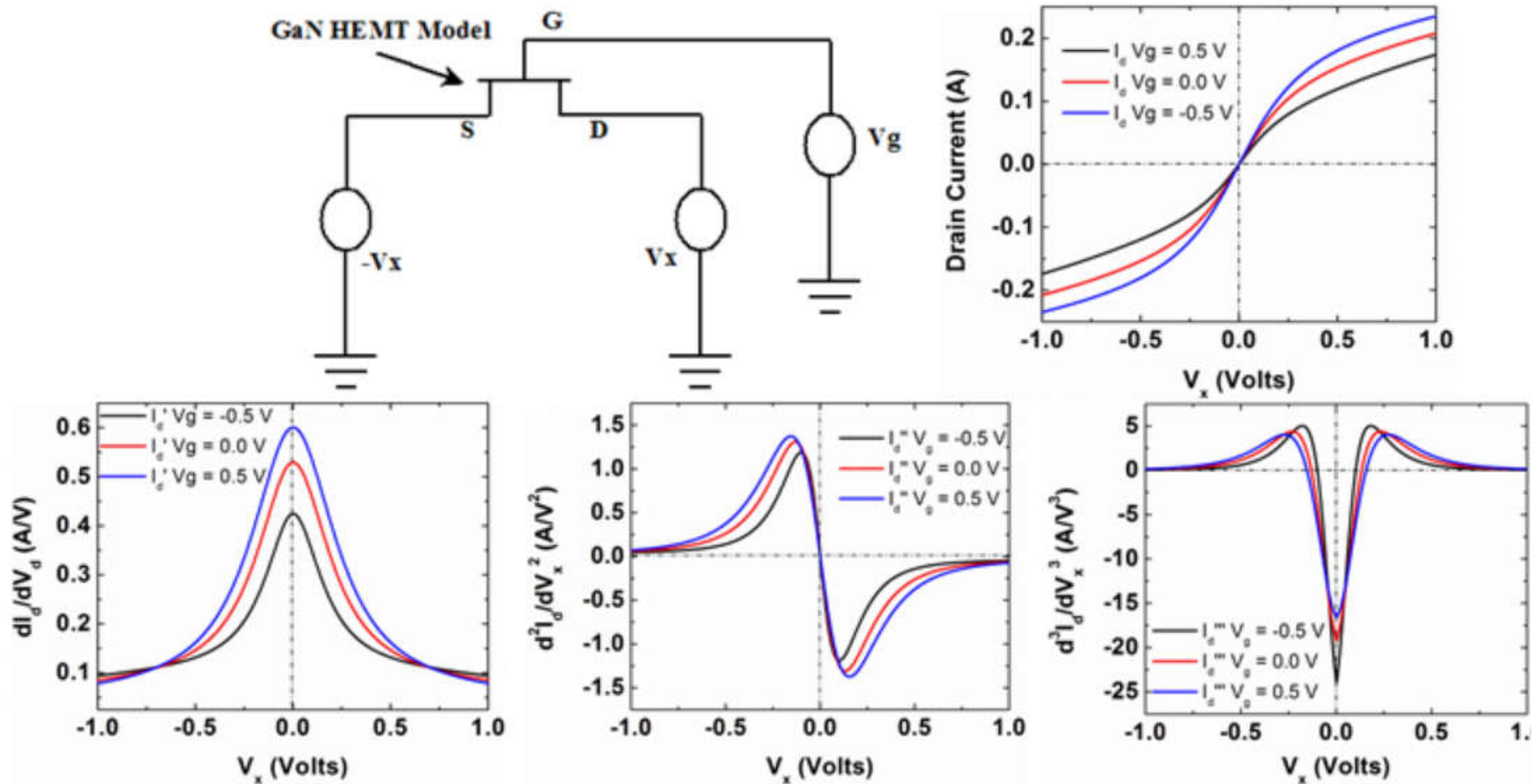


**Good model behavior up-to rated 30 A tested at device and circuit level**

# ASM GaN Model Quality Testing

# ASM GaN Model

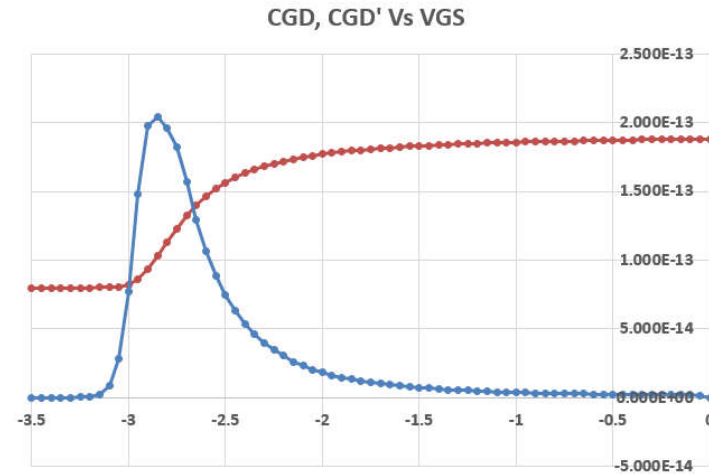
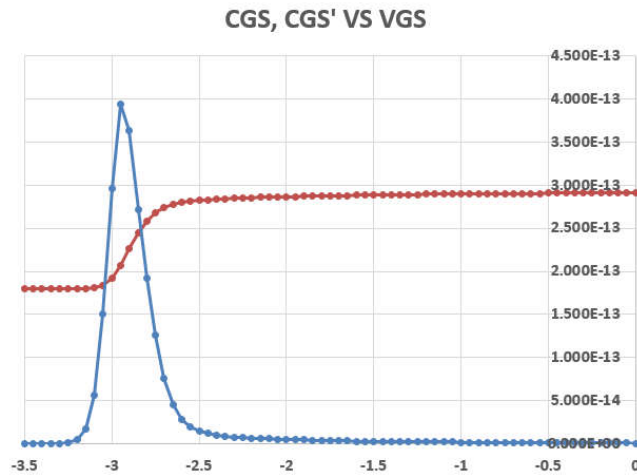
## MODEL QUALITY TESTING



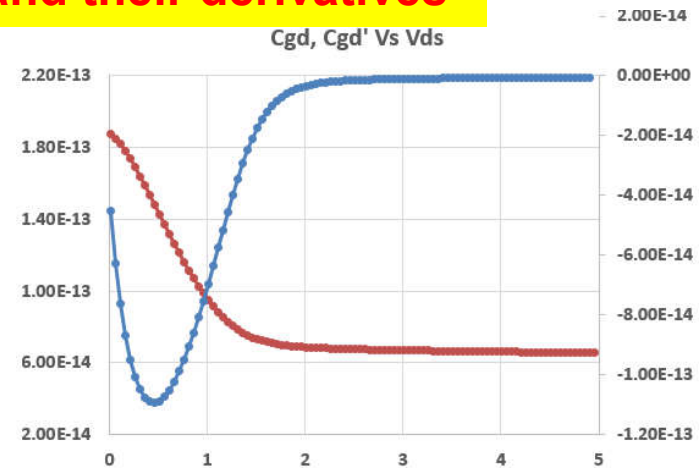
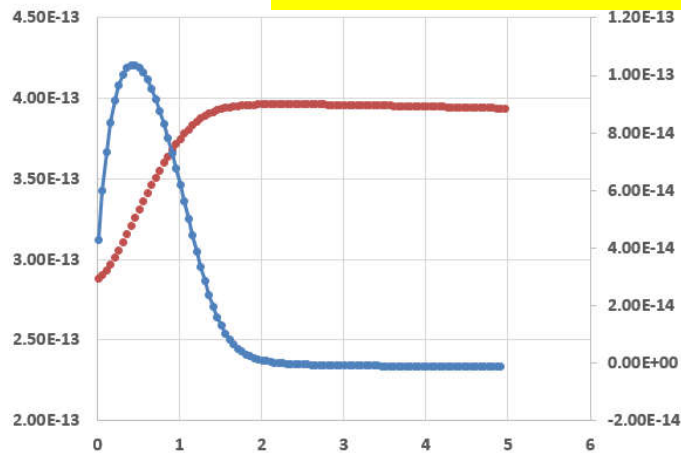
**Model passes symmetry and continuity tests**

# ASM GaN Model

## MODEL QUALITY TESTING



**Smooth Capacitance and their derivatives**



# ASM GaN Model

## KEY MODEL FEATURES

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- Industry standard model for RF and power GaN devices
- Physical basis of formulations and model parameters
- Model captures various aspects of GaN devices
  - DC currents ( $I_D$  and  $I_G$ )
  - CV (intrinsic and extrinsic capacitance)
  - Noise (Flicker and thermal) (LNA's)
  - Trapping effects
  - Ambient temperature effects
  - Self-heating effects
  - Configurable field-plate model
- Demonstrated accuracy and model quality on commercial grade devices
- **Download link:**  
**<https://research.science.mq.edu.au/edac/asm-code/>**

# Thank You!