Nov.30, 2017

International Conference on Mechanical,
Electrical and Medical Intelligent System 2017

A Novel Approach for Velocity Saturation Calculation of 90nm N-channel MOSFET

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Innovation & Achievement

Focusing

Extraction method of v_{sat}

(v_{sat} : velocity saturation parameter)

✓Physical approach

- Reduced development time
- Application to many kind of field-effect transistors

Outline

- Research Objective
- Derivation of v_{sat} in a Nanometer MOSFET
- Velocity Saturation Extraction Method with Measurements
- Correction and Verification
- Conclusion

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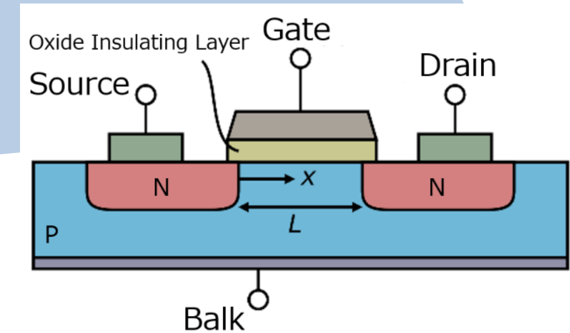
The Importance of Device Modeling

Transistor Modeling



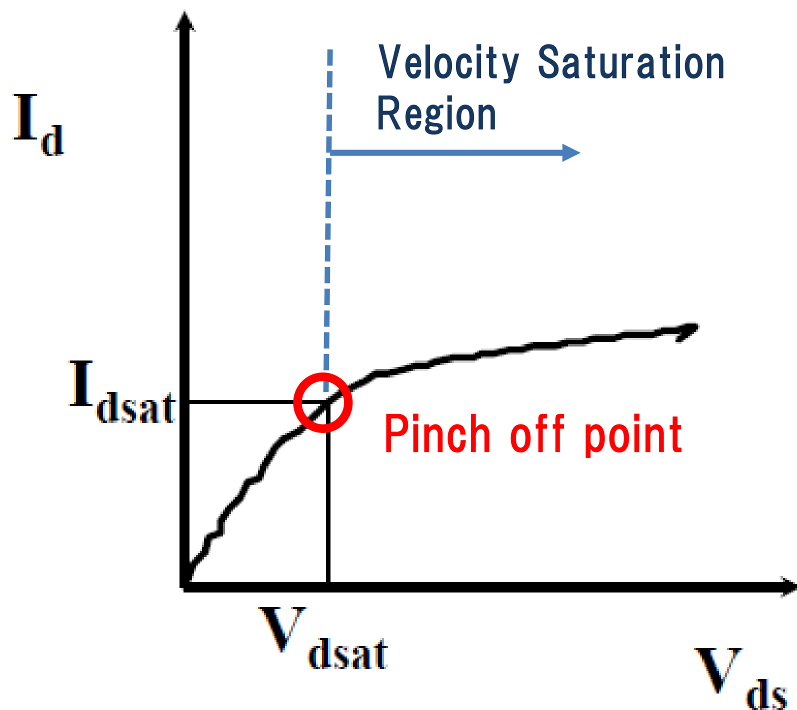
Can Simulate Circuits Correctly

Reduce the number of Prototypes

Cost and Time Reduction

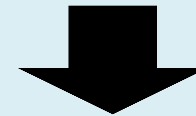
Velocity Saturation (v_{sat})

The property: the carrier velocity reaches the limit when the lateral electric field of the channel in a MOSFET becomes very high.



Key parameter without numerical extraction

Fitting with experience of engineers



Physical extraction method

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Flow of Derivation of v_{sat}

Derive a formulas of v_{sat} using BSIM4

Extracting other required DC parameters

Compare v_{sat} with measurement data

Review v_{sat} extraction method again

Compare v_{sat} with measurement data again

BSIM4 : Berkeley Short-channel IGFET Model

Review of v_{sat}

From BSIM4 model

$$\mathrm{V_{ds,sat}} = \frac{V_{gst}}{A_{bulk}} \quad (1)$$

$$\mathrm{I_{ds}} = \frac{\mathrm{W_{eff}}}{\mathrm{L_{eff}}} \mu_{\mathrm{eff}} \mathrm{C_{ox}} \left(\mathrm{V_{gst}} \cdot \mathrm{V_{ds}} - \frac{1}{2} \mathrm{A_{bulk}} \mathrm{V_{ds}^2} \right) \quad (2)$$

Internal variable of bulk charge: A_{bulk}

$$\mathrm{A_{bulk}} = \left(1 + \frac{\mathrm{K_1}}{2\sqrt{(\emptyset_s - V_{bs})}} \left(\frac{(A_0 L_{eff})}{L_{eff} + 2\sqrt{X_j X_{dep}}} \left(1 - A_{gs} V_{gst} \left(\frac{L_{eff}}{L_{eff} + 2\sqrt{X_j X_{dep}}} \right)^2 \right) + \frac{B_0}{W_{eff} + B_1} \right) \right) \cdot \frac{1}{1 + K_{ETA} V_{be}} \quad (3)$$

A_{bulk} becomes “1” if L_{eff} is less than 90nm

Derivation of v_{sat}

From the previous formulas

$$\mathrm{I}_{\mathrm{ds,sat}} = W_{eff} C_{ox} \left(V_{gst} - A_{bulk} V_{ds,sat} \right) v_{sat} \quad (4)$$

$$\mathrm{V}_{\mathrm{gst}} = \mathrm{V}_{\mathrm{gs}} - \mathrm{V}_{\mathrm{th}} \quad (5)$$

Velocity saturation v_{sat} $(L_{eff} < 90nm)$

$$v_{\mathrm{sat}} = \frac{\mathrm{I}_{\mathrm{ds,sat}}}{W_{eff} C_{ox} (V_{gst} - V_{ds,sat})} \quad (6)$$

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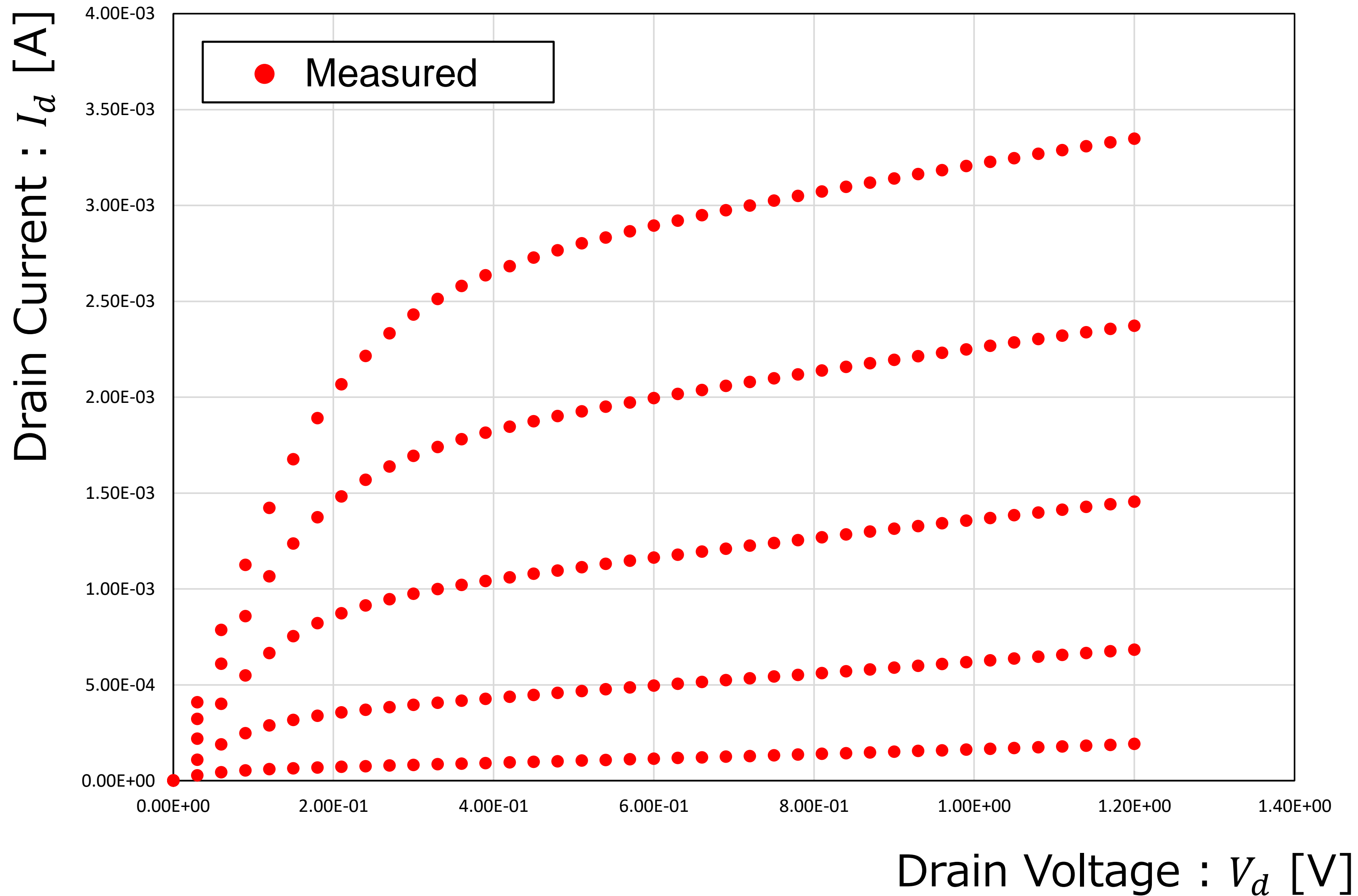
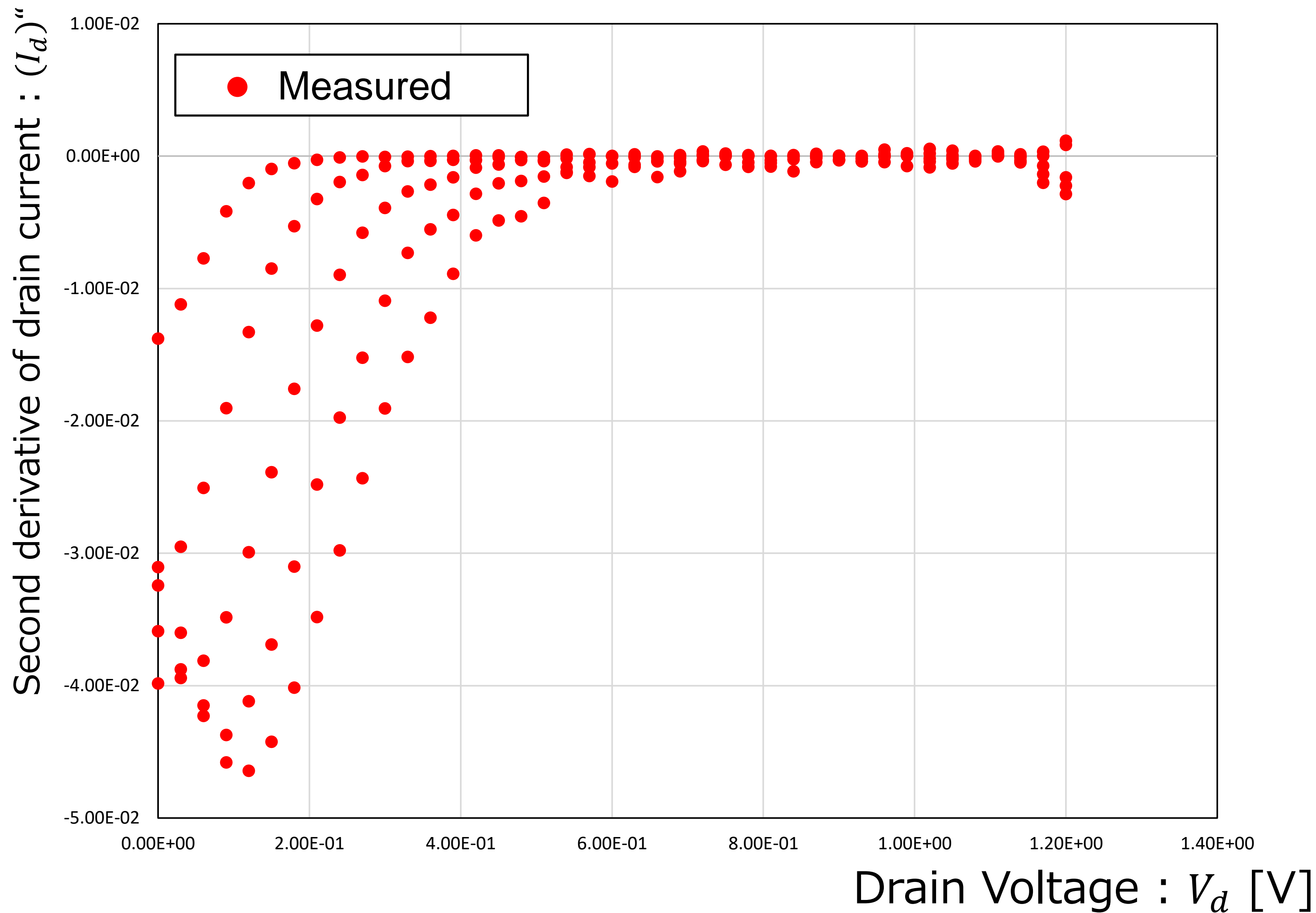
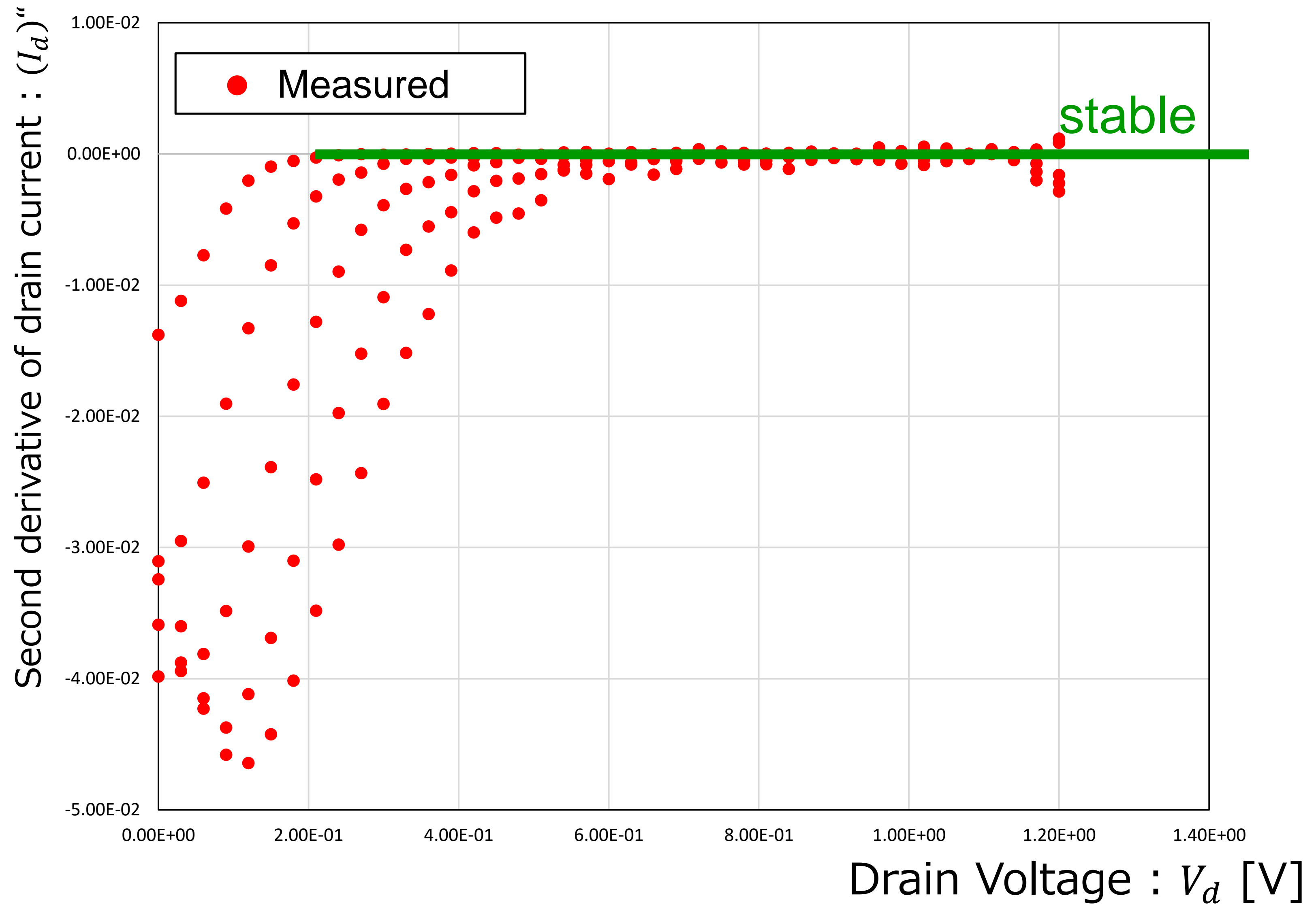
$I_{ds} - V_{ds}$ in a 90nm MOSFET



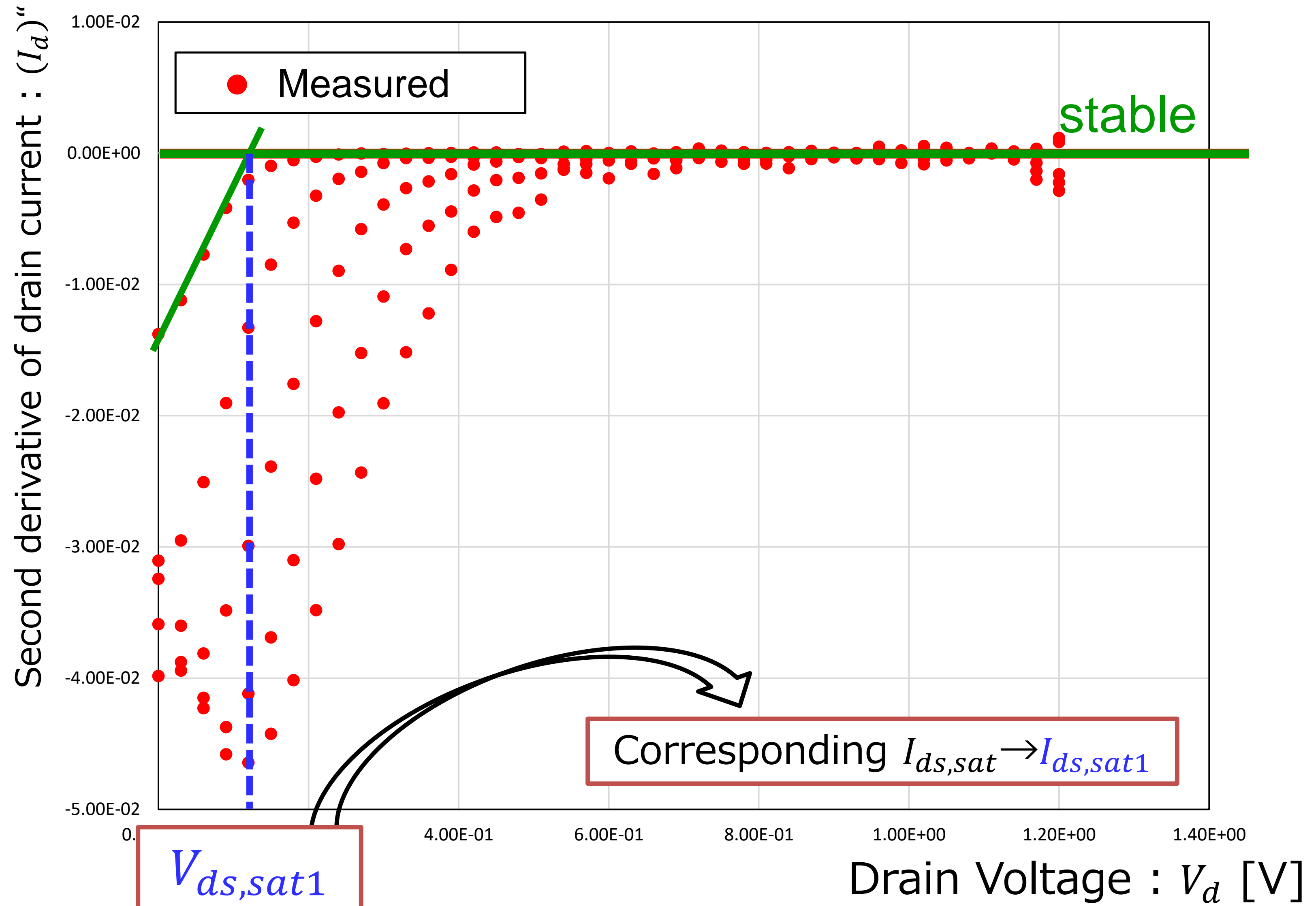
$I_{ds} - V_{ds}$ in a 90nm MOSFET Second Derivative



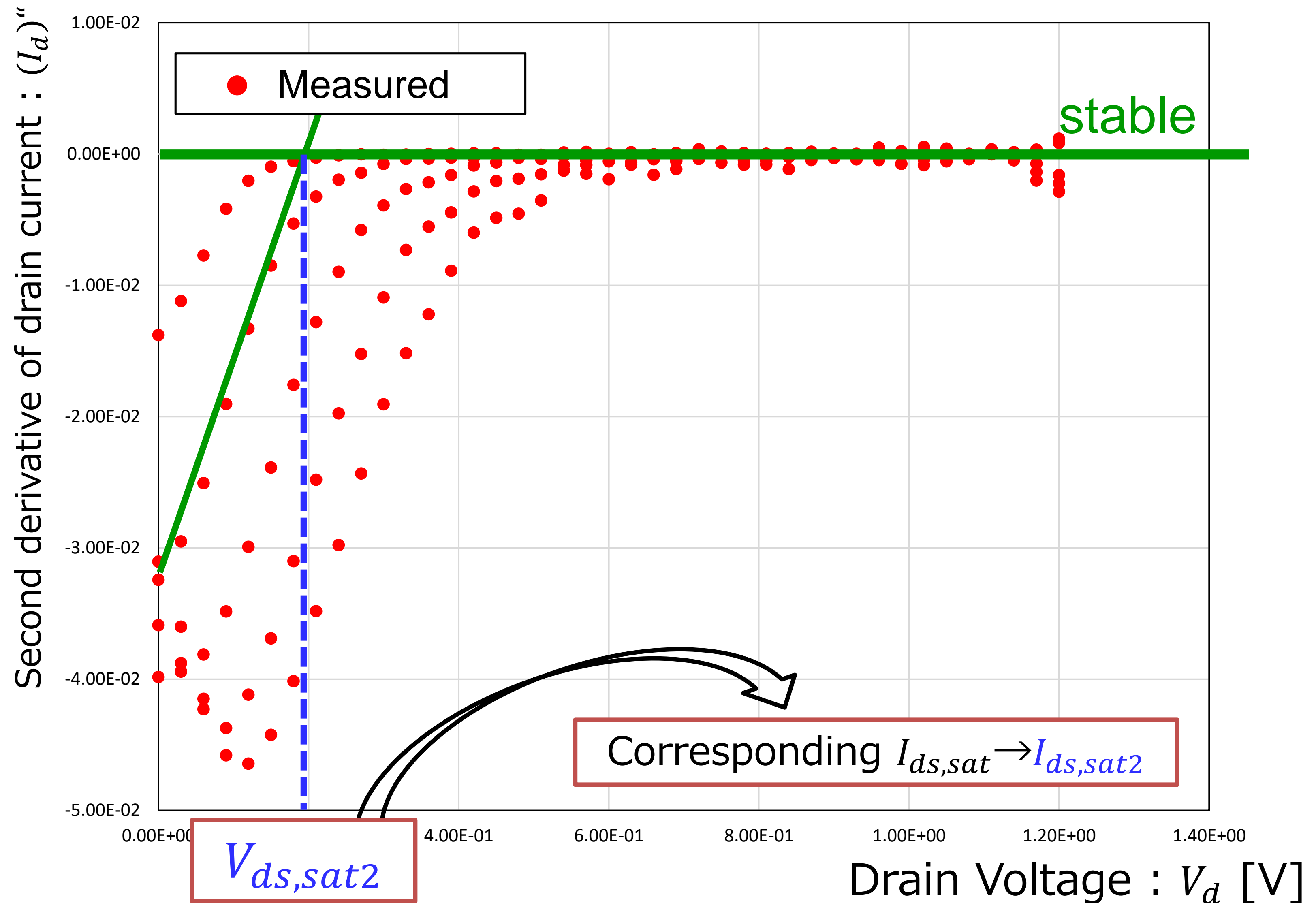
$I_{ds} - V_{ds}$ in a 90nm MOSFET Peak Detection



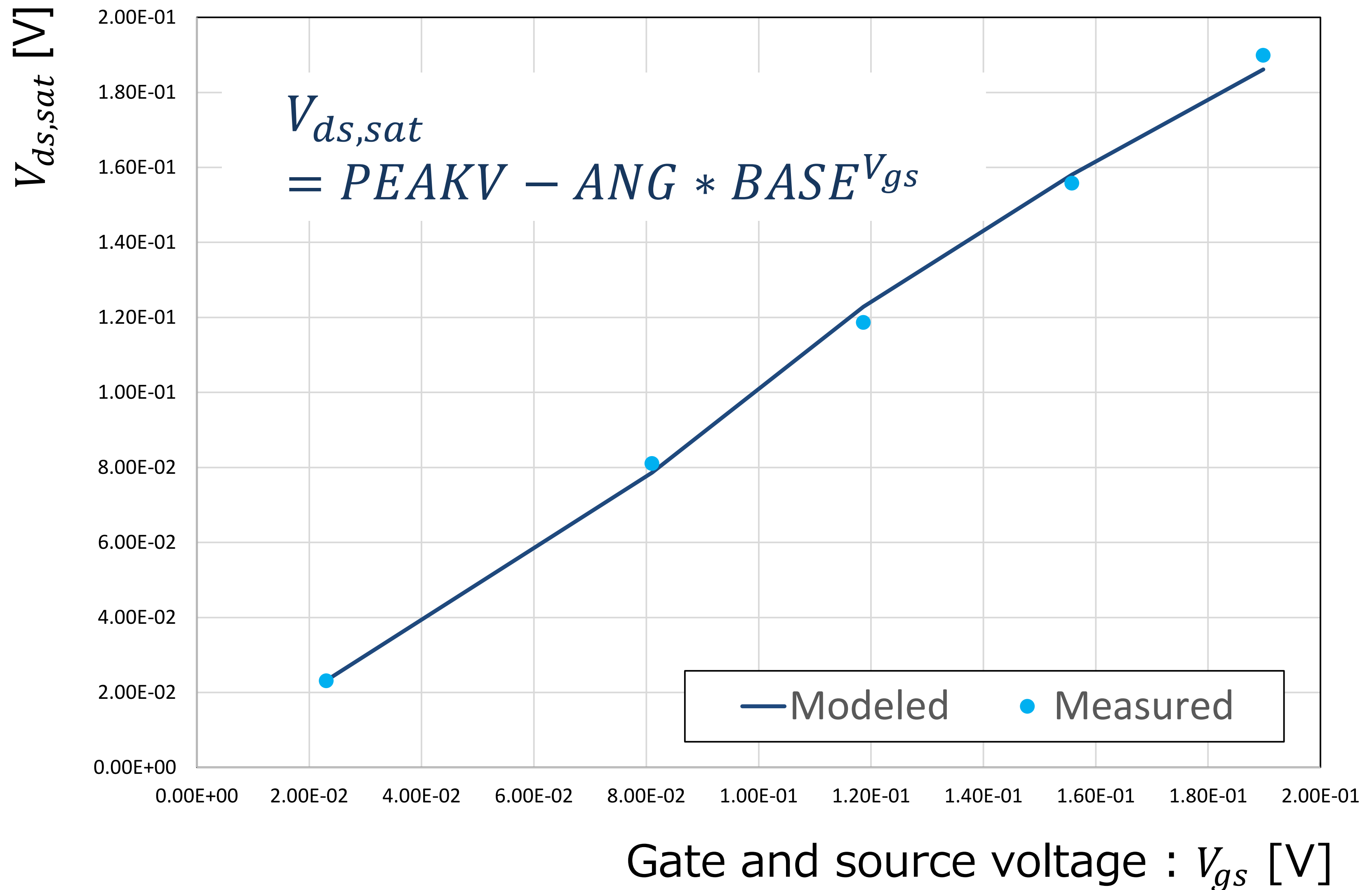
$I_{ds} - V_{ds}$ in a 90nm MOSFET Derivation of $V_{ds,sat}$



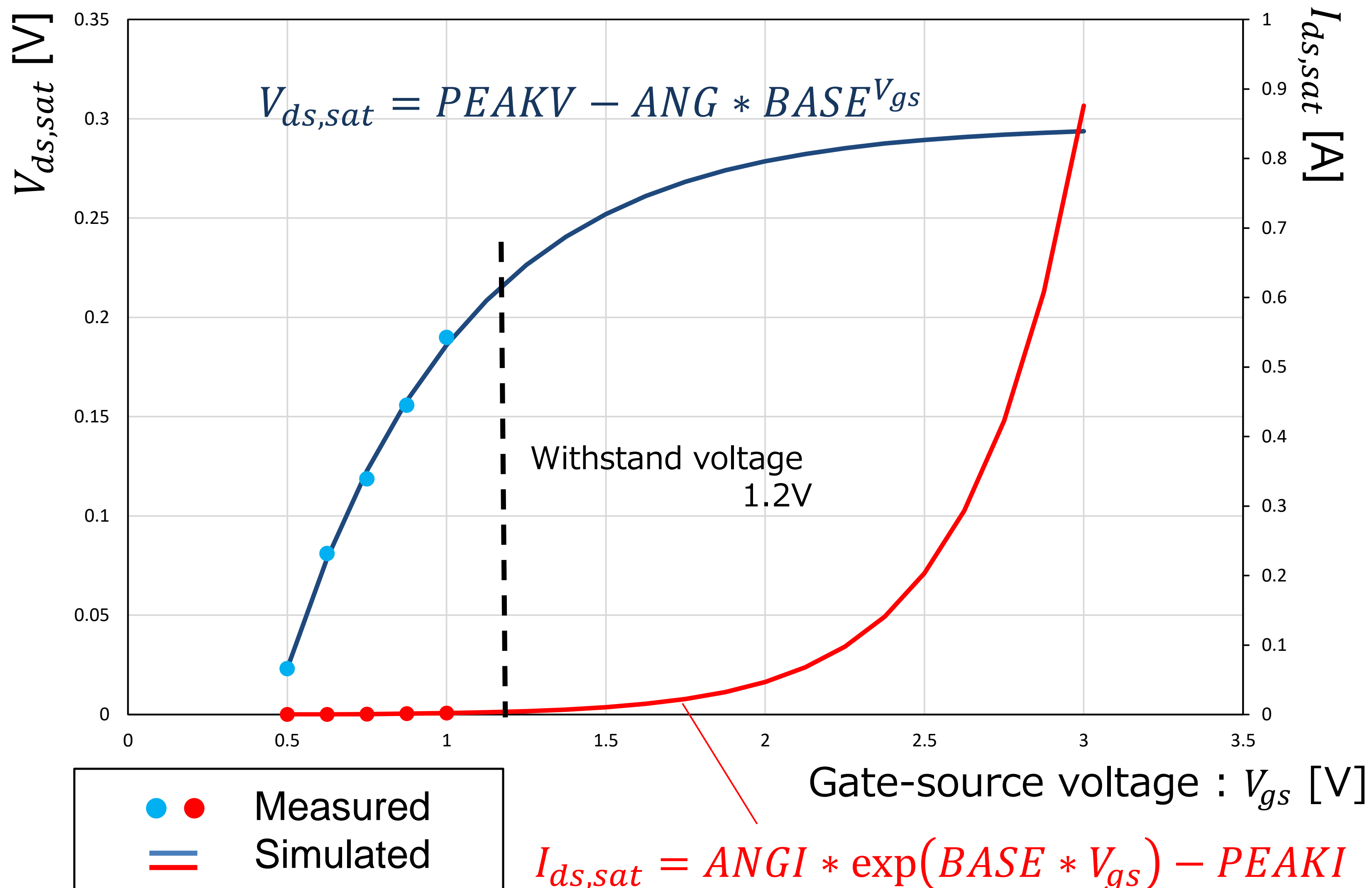
$I_{ds} - V_{ds}$ in a 90nm MOSFET Derivation of $V_{ds,sat}$



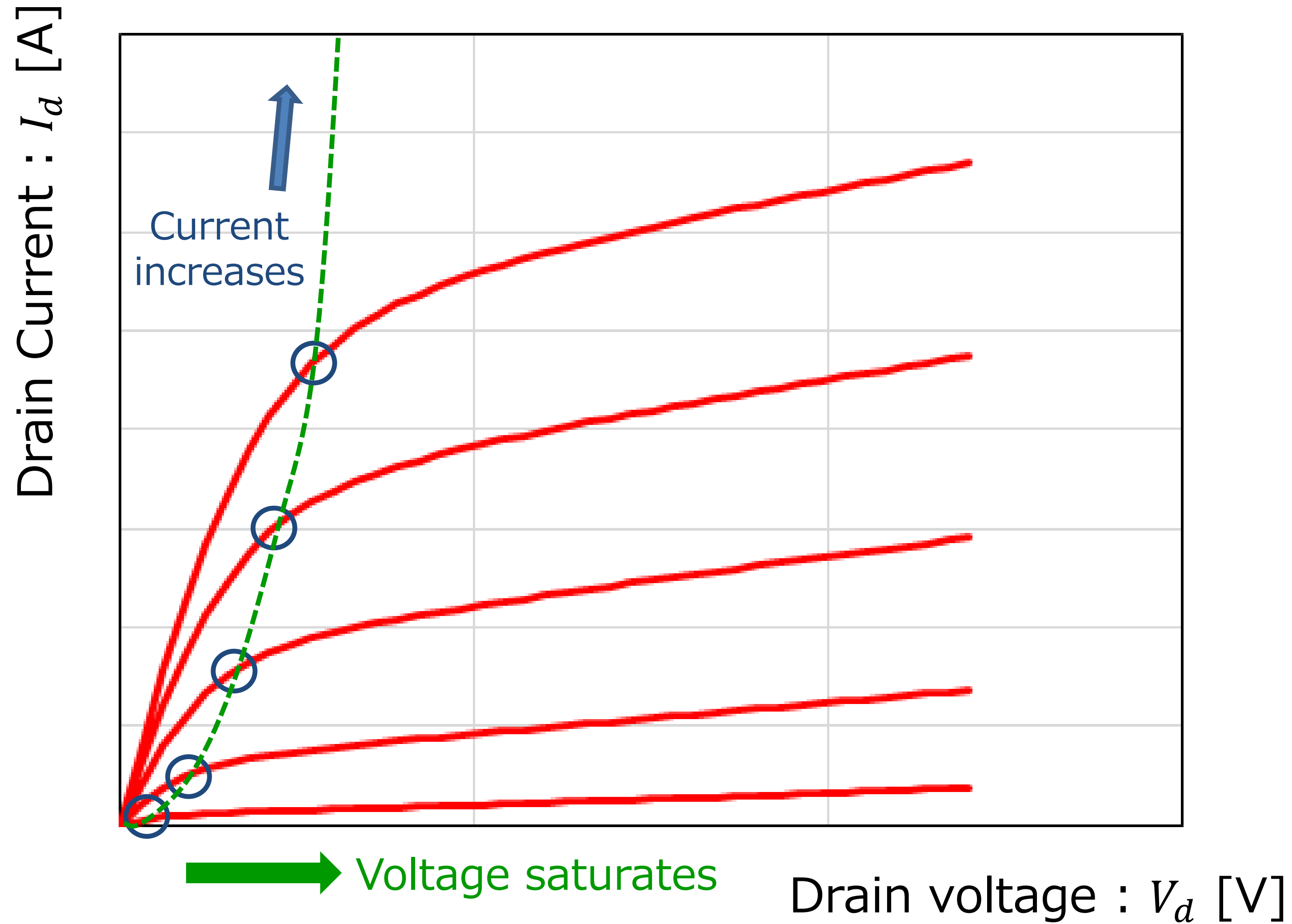
Fitting of $V_{ds,sat}$



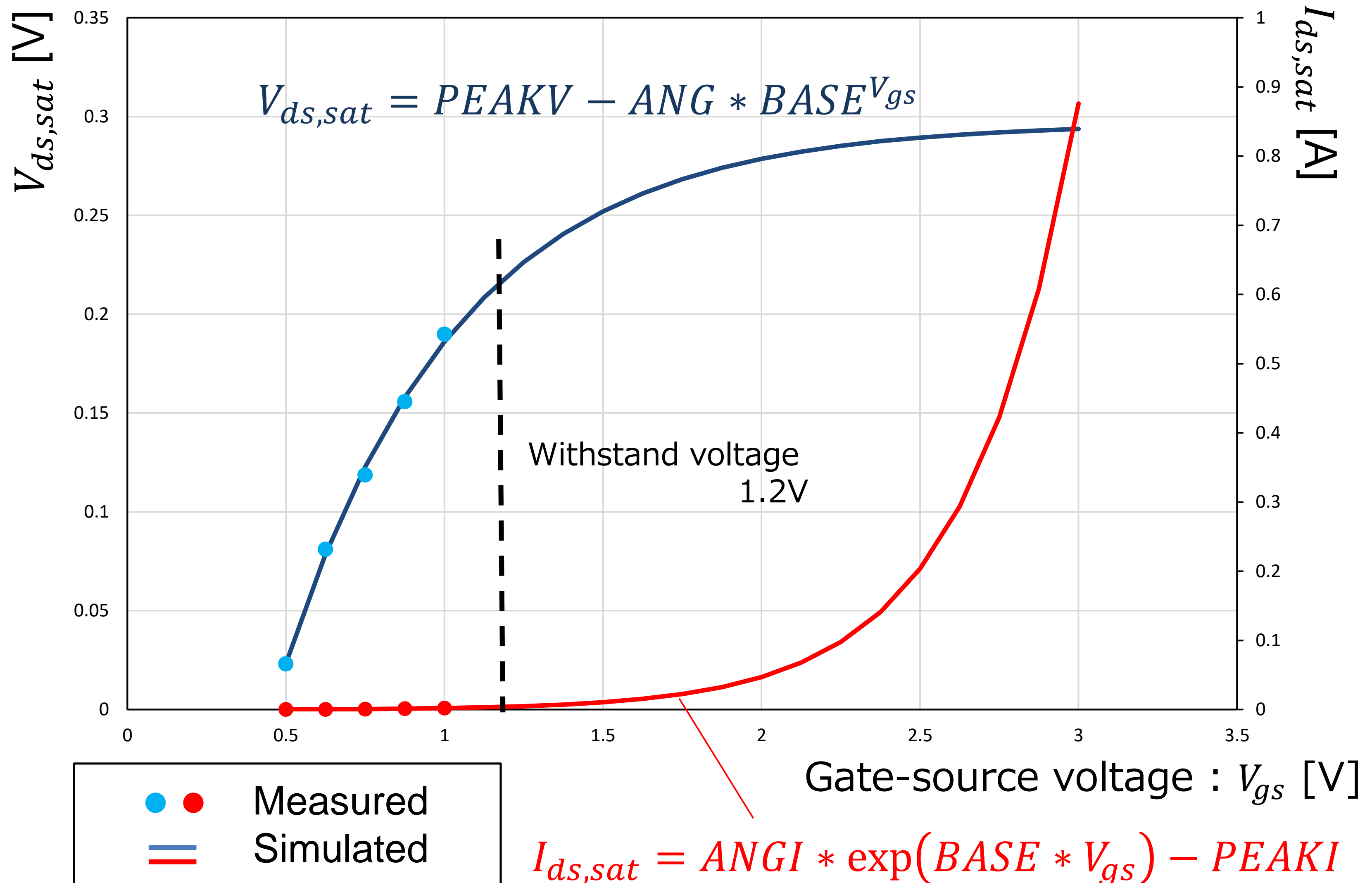
Graph of $I_{ds,sat}, V_{ds,sat}$



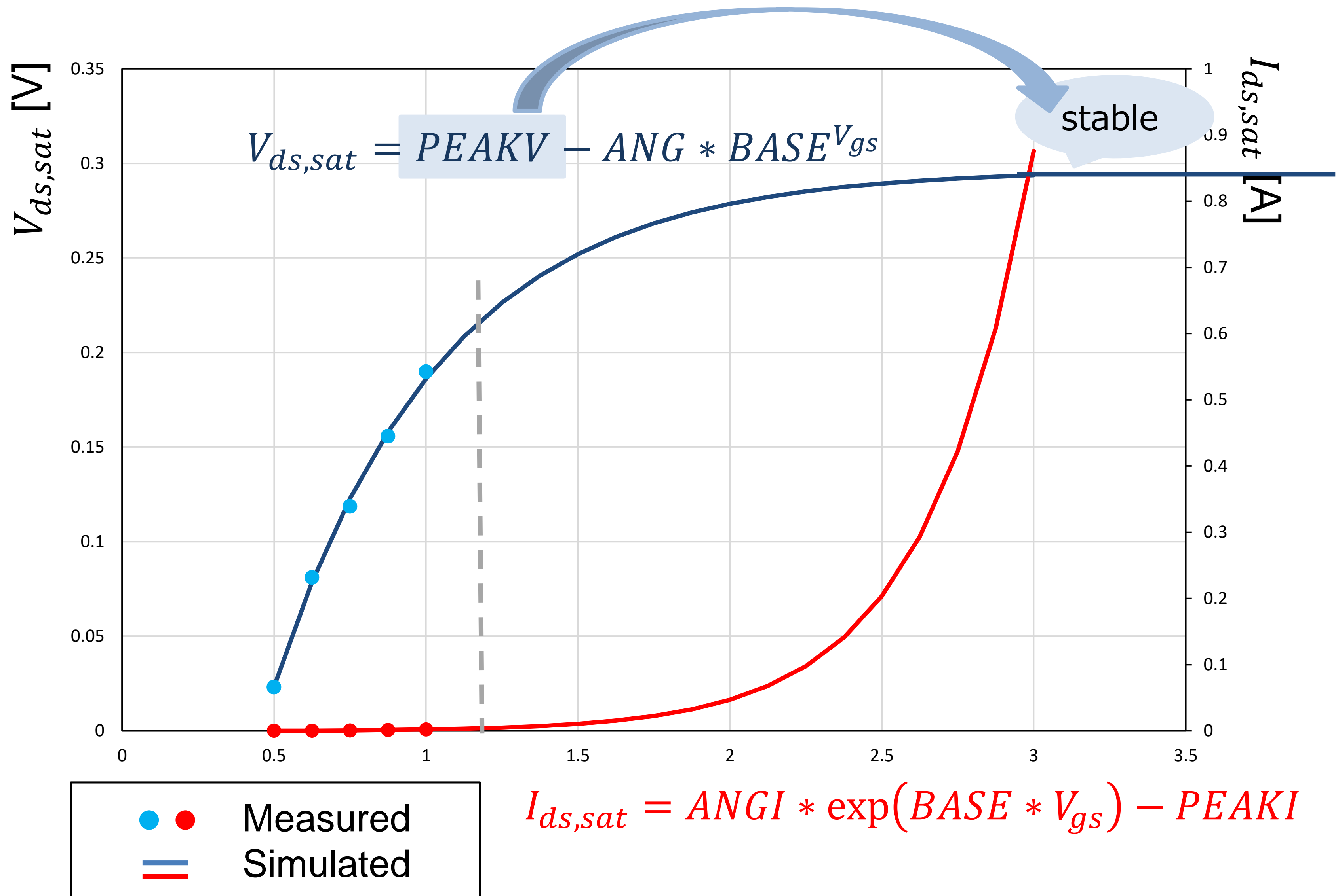
Consideration of Fitting of $V_{ds,sat}$, $I_{ds,sat}$



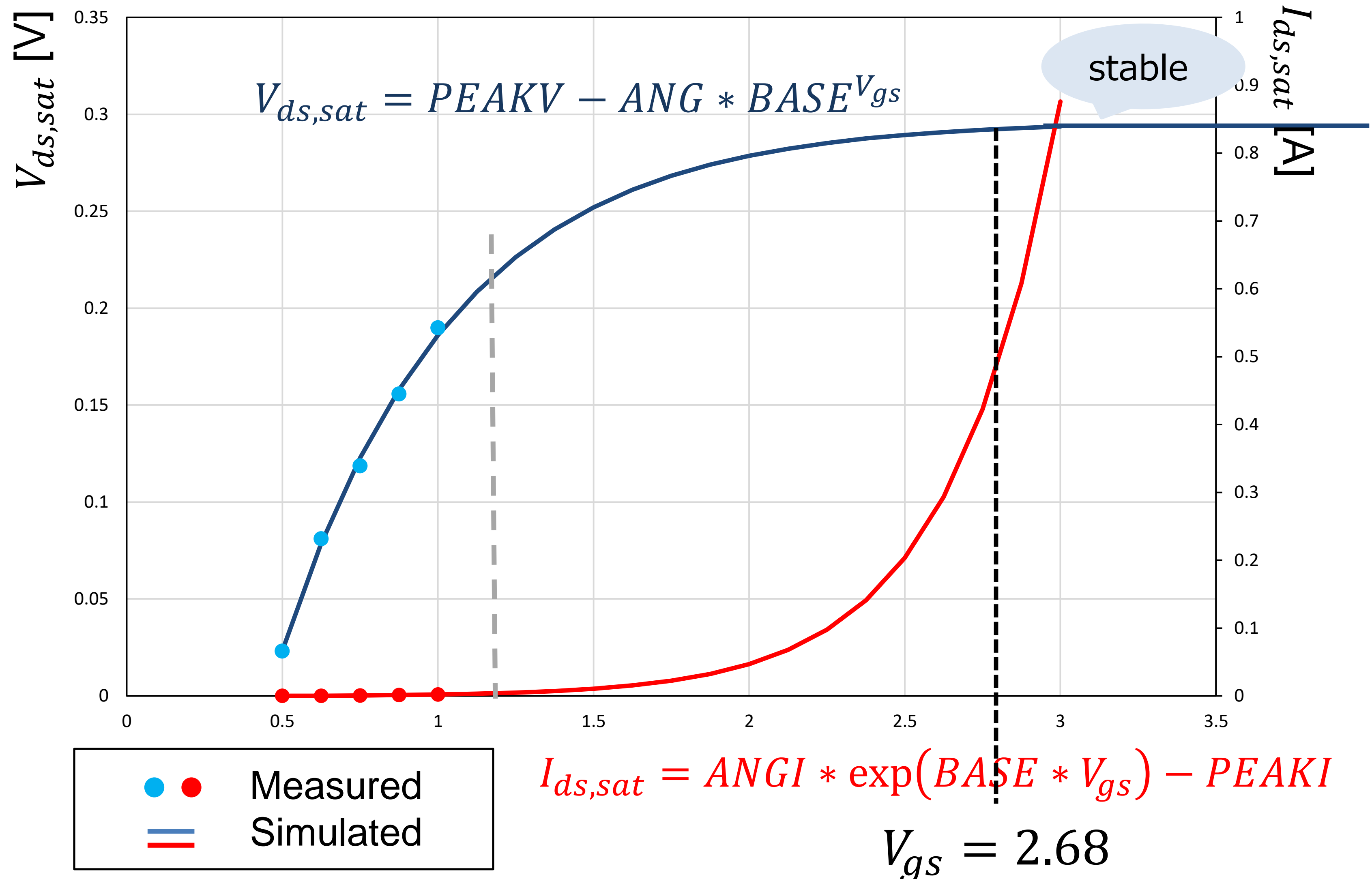
Graph of $I_{ds,sat}, V_{ds,sat}$



Graph of $I_{ds,sat}, V_{ds,sat}$ Obtain Value of $V_{ds,sat}$



Graph of $I_{ds,sat}, V_{ds,sat}$ Obtain Value of $I_{ds,sat}, V_{gs}$



Examination of v_{sat} Expression

From the previous formula

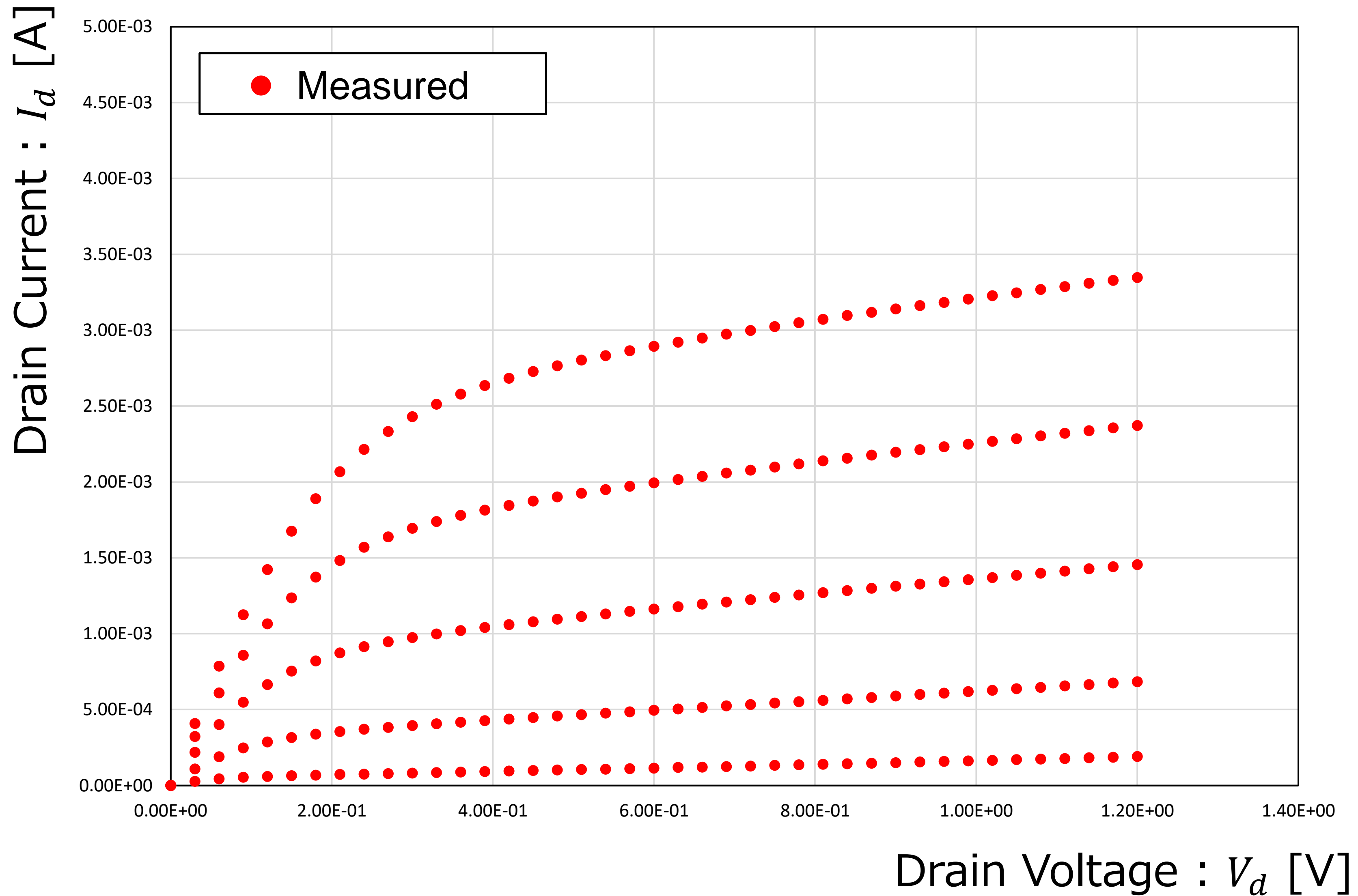
$$\mathrm{I_{ds,sat}} = W_{eff}C_{ox}(V_{gst} - A_{bulk}V_{ds,sat})v_{sat} \quad (4)$$

$$\mathrm{V_{gst}} = \mathrm{V_{gs}} - \mathrm{V_{th}} \quad (5)$$

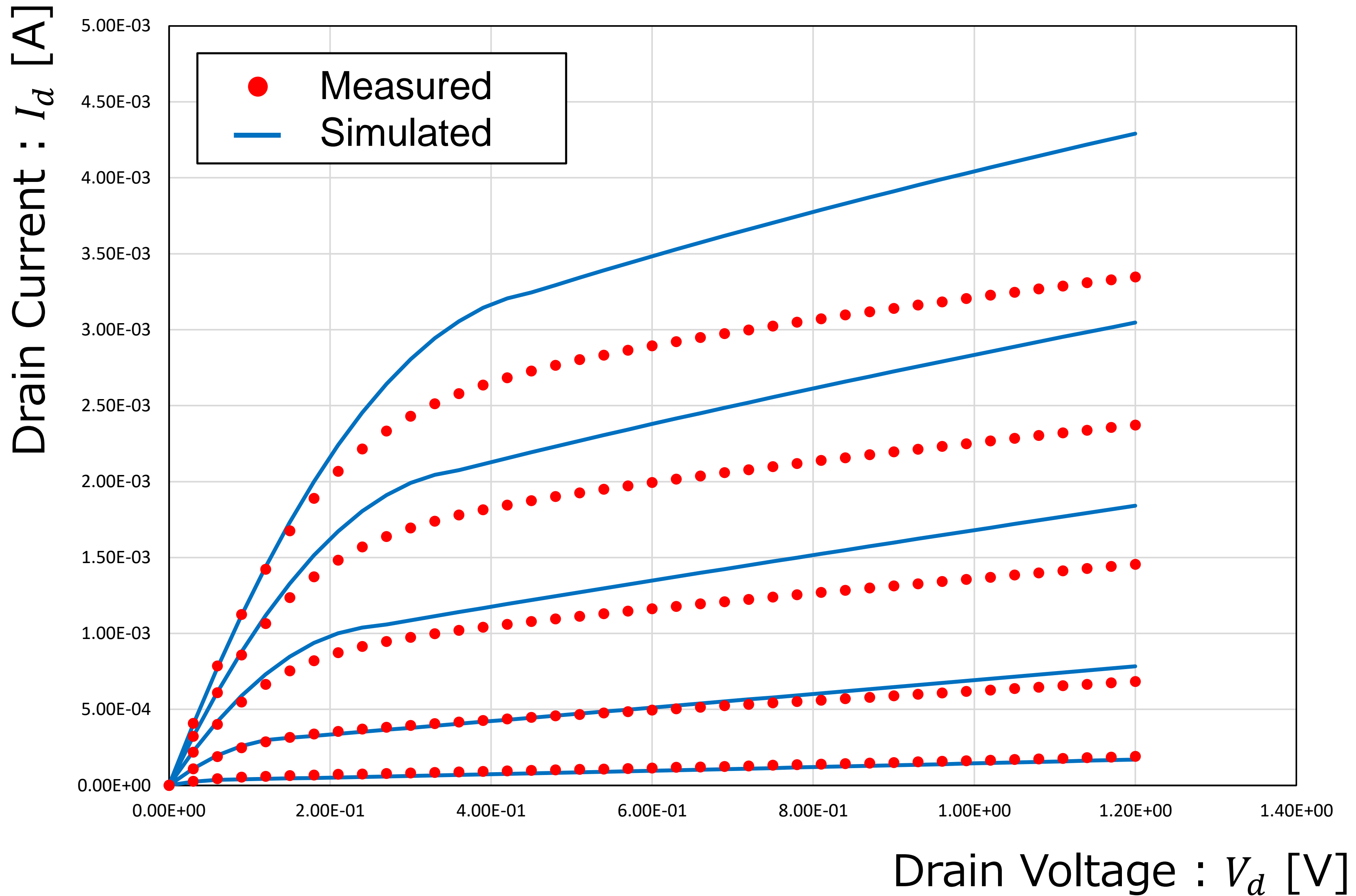
Velocity saturation v_{sat} $(L_{eff} < 90nm)$

$$\mathrm{v_{sat}} = \frac{\mathrm{I_{ds,sat}}}{W_{eff}C_{ox}(V_{gst} - V_{ds,sat})} \quad (6)$$

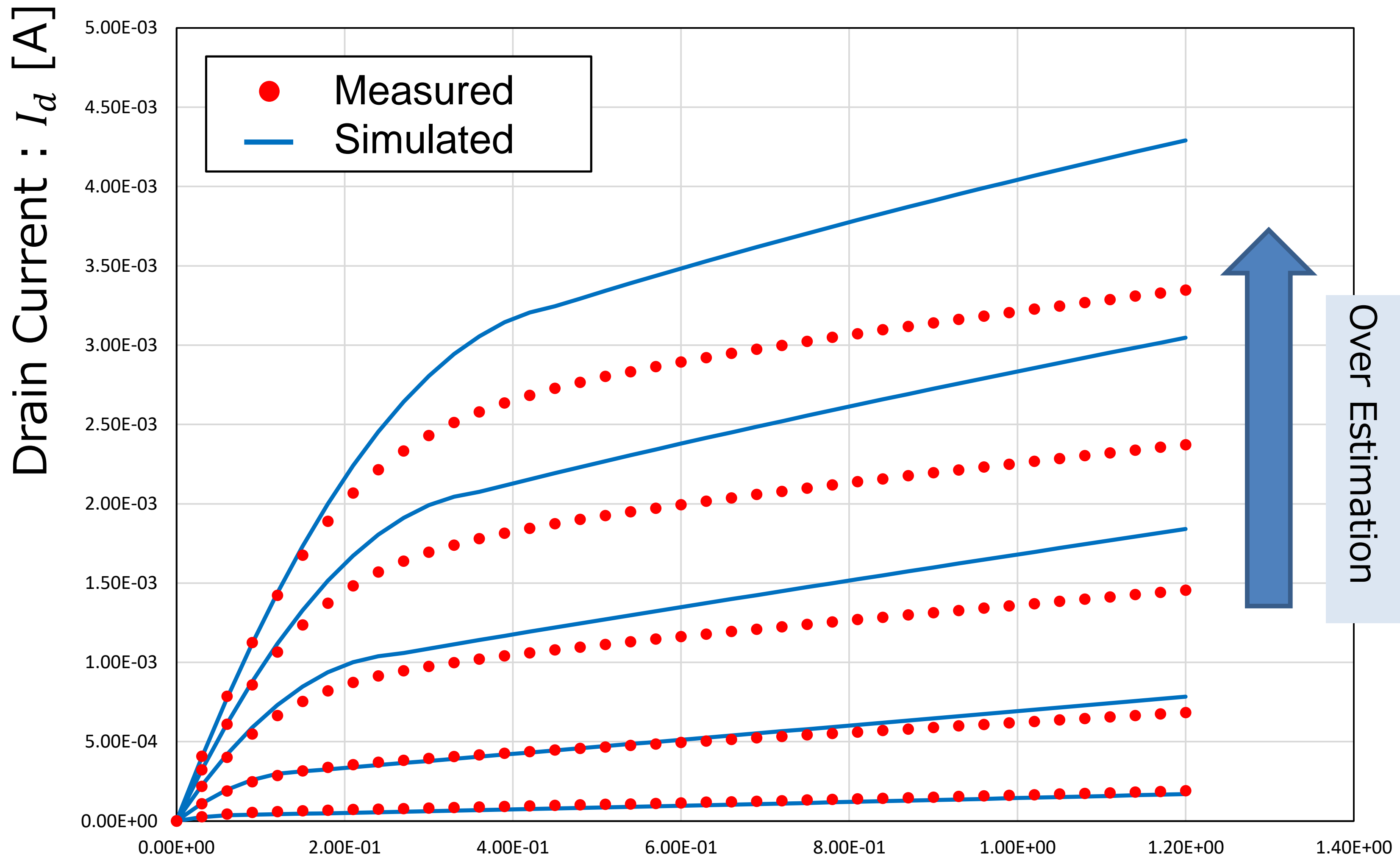
$I_d - V_d$ in a 90nm MOSFET



Comparison Measurement with Simulation Using the Extraction Result of v_{sat}



Consideration on Comparison Result



Contact resistance and bias dependent resistance of LDD diffusion layer are in series

These resistances cause some voltage drops

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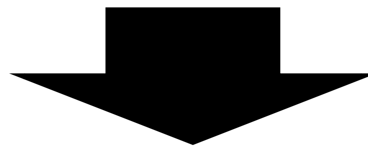
Correction by Series Resistances

From BSIM4 model

$$V_{ds,sat,new} = V_{ds,sat} - \left(\underline{RDSW} \cdot W_{eff} \cdot 100 + \underline{R_X}\right) \cdot I_{ds,sat}$$

Resistances of diffusion and LDD layer

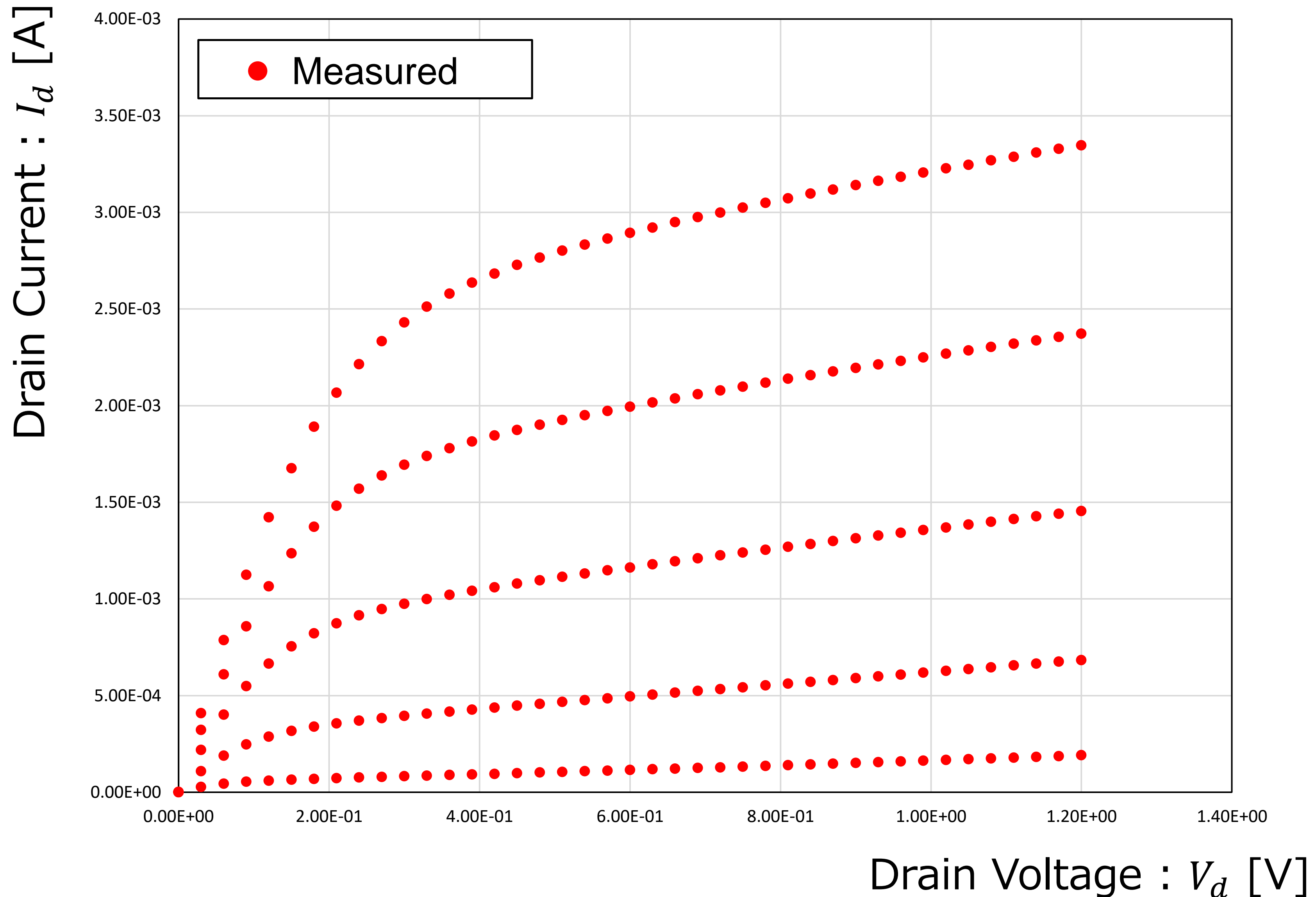
Sum of source and drain contact resistances



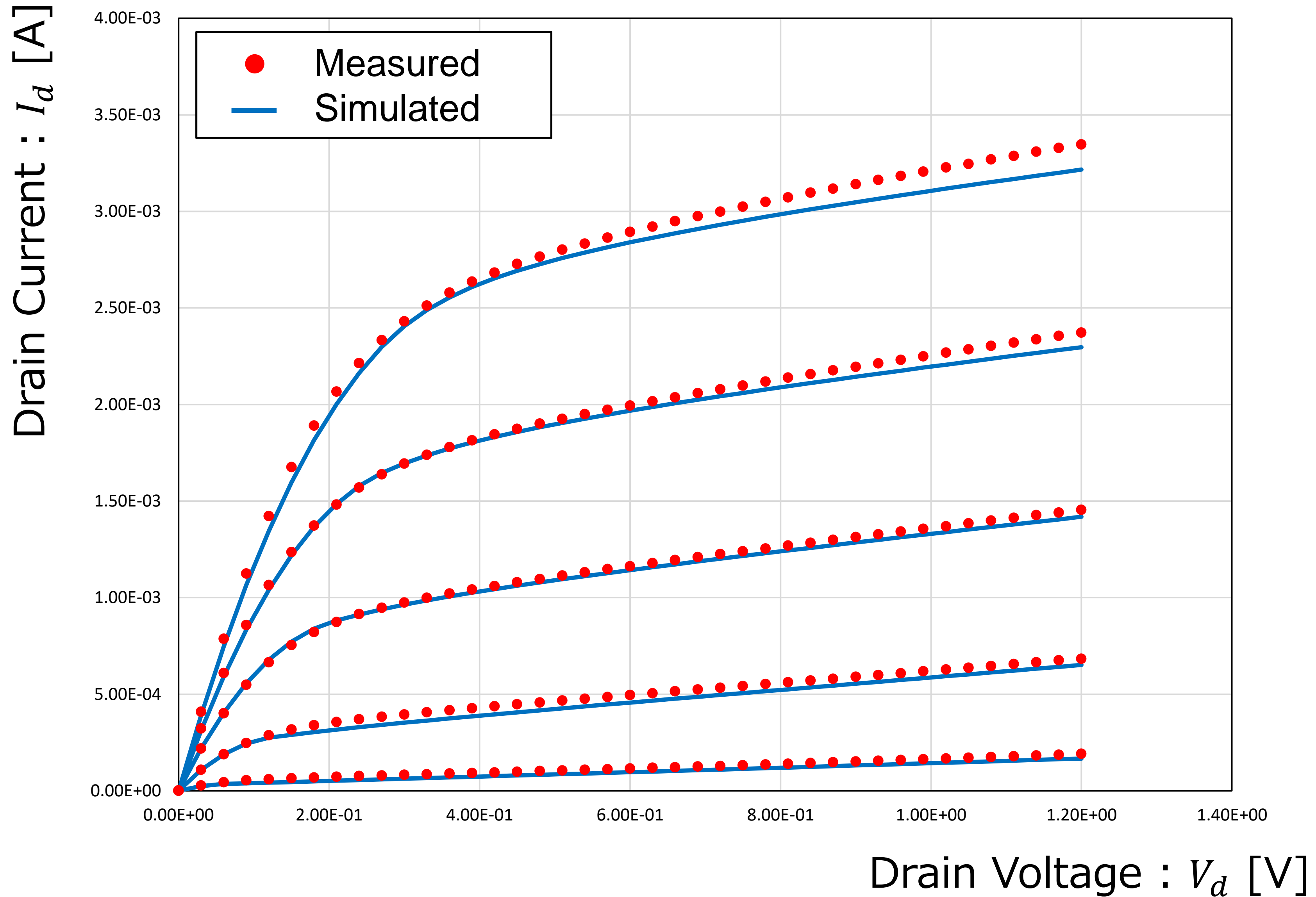
Recalculate v_{sat}

$$v_{sat} = \frac{I_{ds,sat}}{W_{eff} C_{ox} (V_{gst} - V_{ds,sat,new})}$$

$I_d - V_d$ in a 90nm MOSFET



Comparison Measurement with Simulation Using Re-Extraction Result of v_{sat}



Achievement

By fitting

$$v_{\mathrm{sat}} = \frac{\mathrm{I}_{\mathrm{ds,sat}}}{W_{eff}C_{ox}(V_{gst} - V_{ds,sat})}$$

$V_{gs}, V_{ds,sat}, I_{ds,sat}, RDSW, R_X$

Physical v_{sat} extraction method

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Conclusion

- Focus on velocity saturation v_{sat}
- Derivation of v_{sat} from BSIM4 model
- Consider the influence of series resistances
- Re-extract v_{sat} by approximate parameters

Limitations

- In the case of under 90nm devices only
  (only when this condition is satisfied $A_{bulk} \cong 1$)

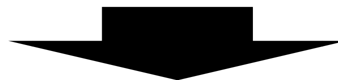
Applicable for recent process devices
Useful also for many other kind of field-effect transistors

Future Work

Develop more accurate series resistances extraction method

Measure multiple devices
with different gate channel length

Study on intrinsic channel resistance
extraction method



Accurate gate bias voltage dependent channel resistance reduction method