

# A New Technique to Extract the S/D Series Resistance of Sub-100nm MOSFETs

**Dominique FLEURY**

**Ph.D. Student**

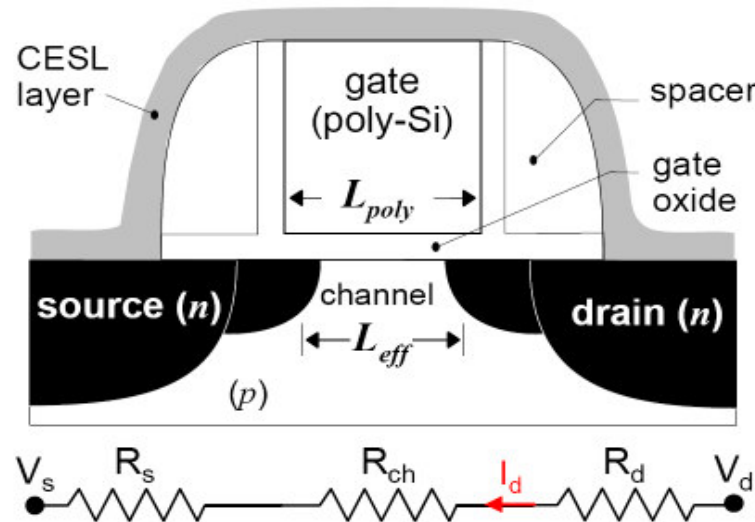
**STMicroelectronics / IMEP-LAHC lab.**

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# Introduction: some definitions

- **Series resistance:**  $R_{sd} = R_s + R_d$  (from the testing pad to the beginning of the channel)
- **Channel resistance:**  $R_{ch}$
- **Total resistance:**  $R_{tot} = R_{ch} + R_{sd}$



# Introduction: the $I_d(V_{gs})$ model

## current factor

returns how many current flows in the channel

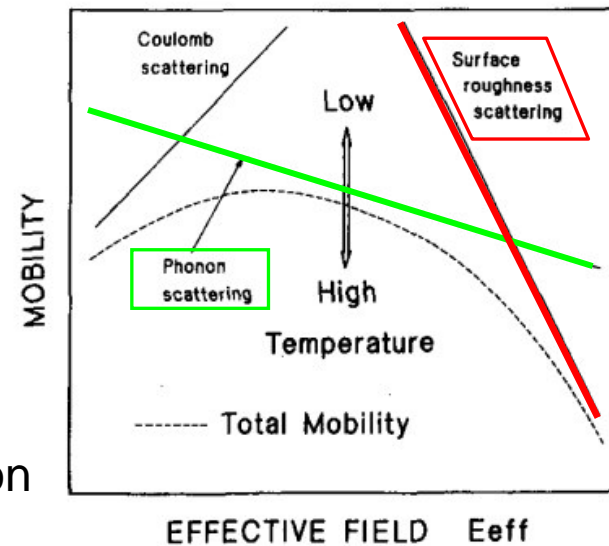
## gate overdrive

bias above the threshold voltage:  $V_{gt} = V_{gs} - V_{th}$

$$I_D = \frac{\beta V_D V_{Gt}}{1 + \underbrace{\Theta_1 V_{Gt} + \Theta_2 V_{Gt}^2}_{\text{Mobility reduction factors}}}$$

## Mobility reduction factors


- model the mobility reduction due to phonon and surface roughness scatterings




# Introduction: the $I_d(V_{gs})$ model

- The current gain factor can be extracted ( $\xi$ -function<sup>[1]</sup> /  $Y$ -function<sup>[2]</sup> / Hamer<sup>[3]</sup>).
- It contains  $L_{eff}$  and  $\mu_0$  so it may be used to make an extraction insensitive to these parameters.

$$\beta = \mu_0 \cdot C_{eff} \frac{W}{L_{eff}}$$

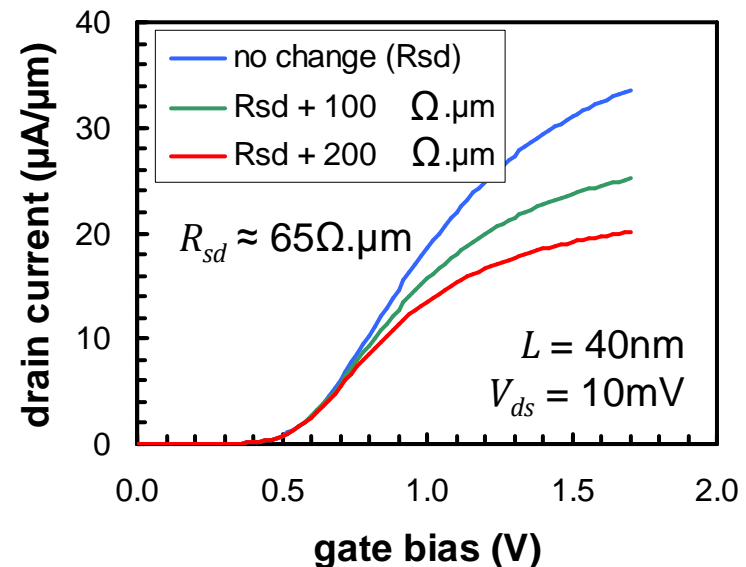
  
 low field mobility
 

  
 effective channel length

# Introduction: why measuring $R_{sd}$ ?

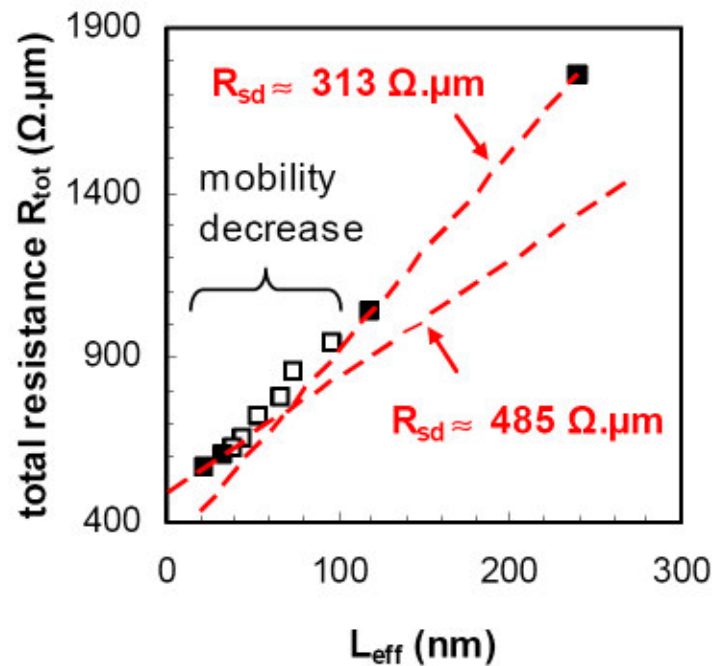
- Essential parameter for performance improvement:
  - A lower  $R_{sd}$  improves the MOSFET performances
- To extract transport parameters:
  - Effective mobility (ex: split  $C-V$  technique)
  - Drift carrier velocity
  - Ballistic rate

Impact of  $R_{sd}$  on the linear drain current



# How to extract $R_{sd}$ ?

- The  $R_{tot}(L)$  technique<sup>[4]</sup>
  - Provides erroneous values when mobility changes from a long to a short channel.

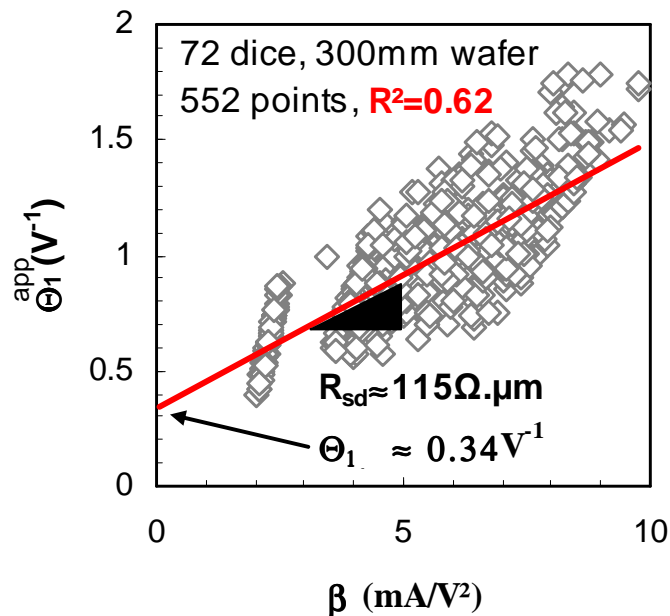


Mobility changes may be due to:

- pocket implants <sup>[5]</sup>
- strain <sup>[6]</sup>
- implantation defects close to S/D junctions <sup>[7]</sup>

# How to extract $R_{sd}$ ?

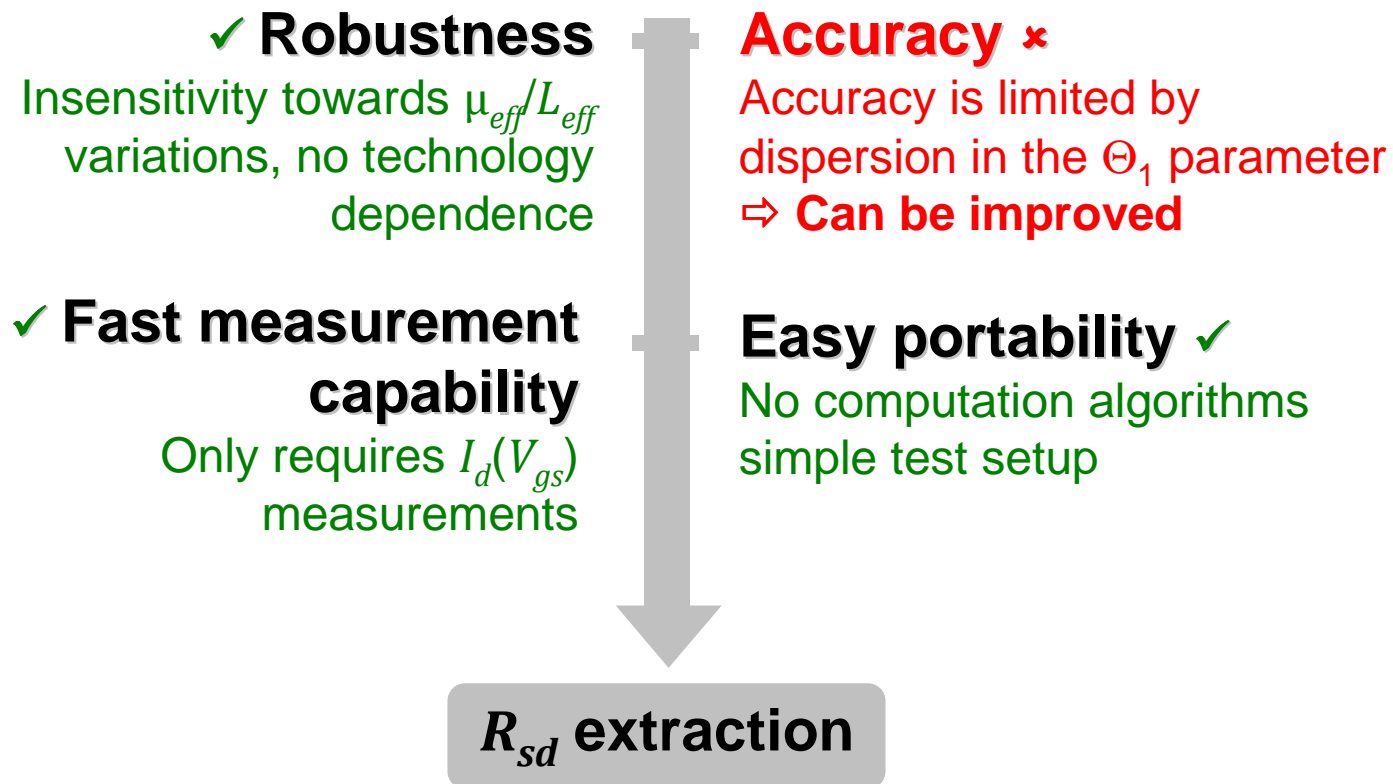
- The  $Y$ -function technique<sup>[2]</sup>
  - Insensitive to mobility variations
  - High dispersion on  $R_{sd}$  due to the  $\Theta_1$ -parameter



$$\Theta_1^{app} = \Theta_1 + \underline{R_{sd}} \cdot \beta$$

# How to extract $R_{sd}$ ?

## ● What can we expect from an extraction methodology in an industrial context ?





# The new technique: $R_{tot}-\beta$

- $R_{tot}$  can be computed as a function of  $1/\beta$

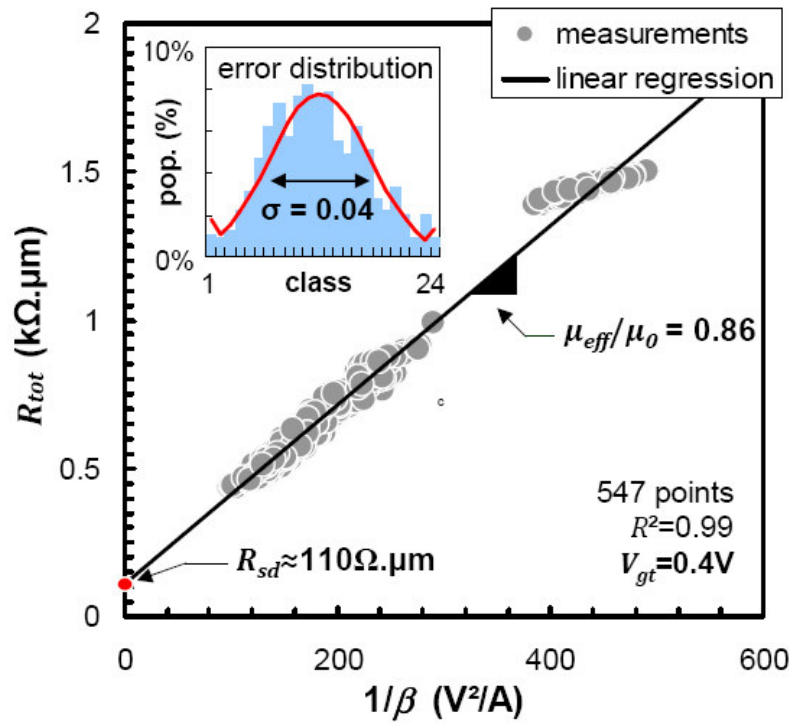
$$R_{tot} = \frac{V_{ds}}{I_d} = \frac{1}{\beta} \left( \frac{1 + \Theta_1 V_{gt} + \Theta_2 V_{gt}^2}{V_{gt}} \right) + R_{sd}(V_{gs})$$

parameter
assumed constant  
for a given  $V_{gt}$ 
result

- When  $R_{tot}$  is plotted versus  $1/\beta$ ,  $R_{sd}$  can be read at the intercept with the  $y$ -axis.

# The new technique: $R_{tot}-\beta$

- $R_{tot}(1/\beta)$  linear regression returns  $R_{sd}$  for the technology (at a given  $V_{gt}$ )

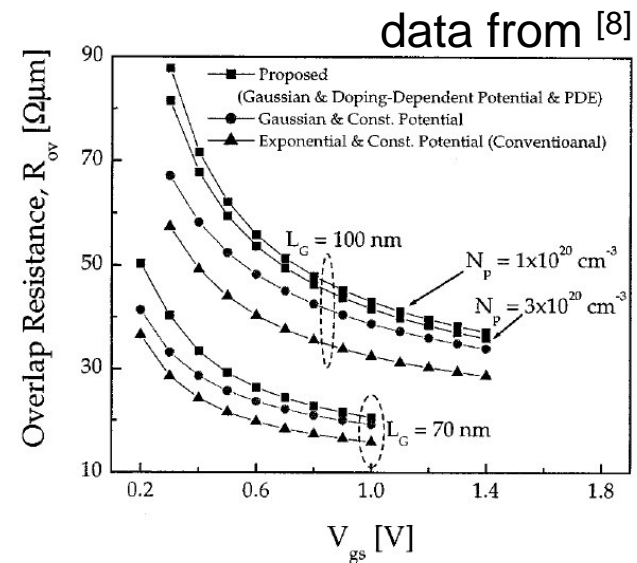
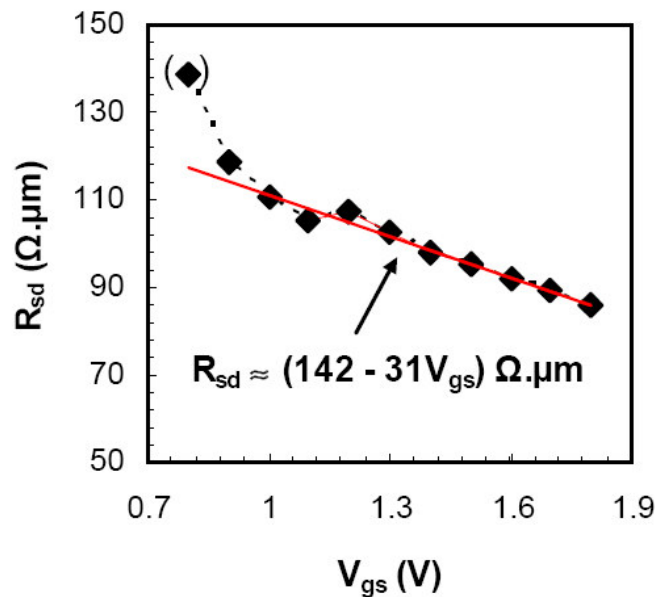


- $R_{sd}$  is read at the intercept (at the given  $V_{gt}$ )
- The mobility attenuation at the given  $V_{gt}$  is read from the slope
- dispersion is very low and accuracy is improved.

# The new technique: $R_{tot}-\beta$

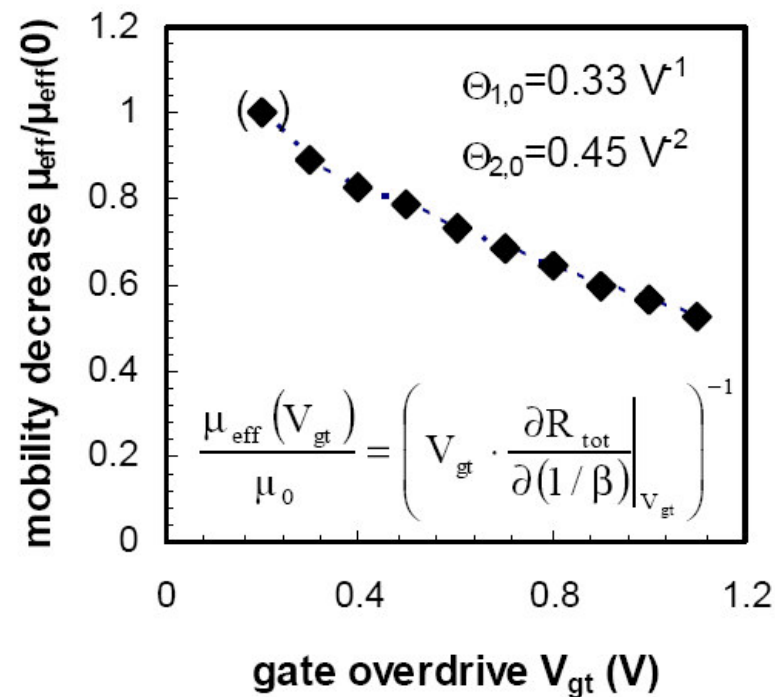
- $R_{sd}$  can be extracted as a function of  $V_{gs}$ 
  - **approximation:**  $V_{gs} \approx V_{gt} + \langle V_{th} \rangle$
  - consistent with  $R_{ov}$  variations of the literature<sup>[8]</sup>

$R_{sd}(V_{gs})$  trend is extracted.



# The new technique: $R_{tot}-\beta$

- Mobility attenuation is extracted from the slope, for the given technology



# The new technique: robustness

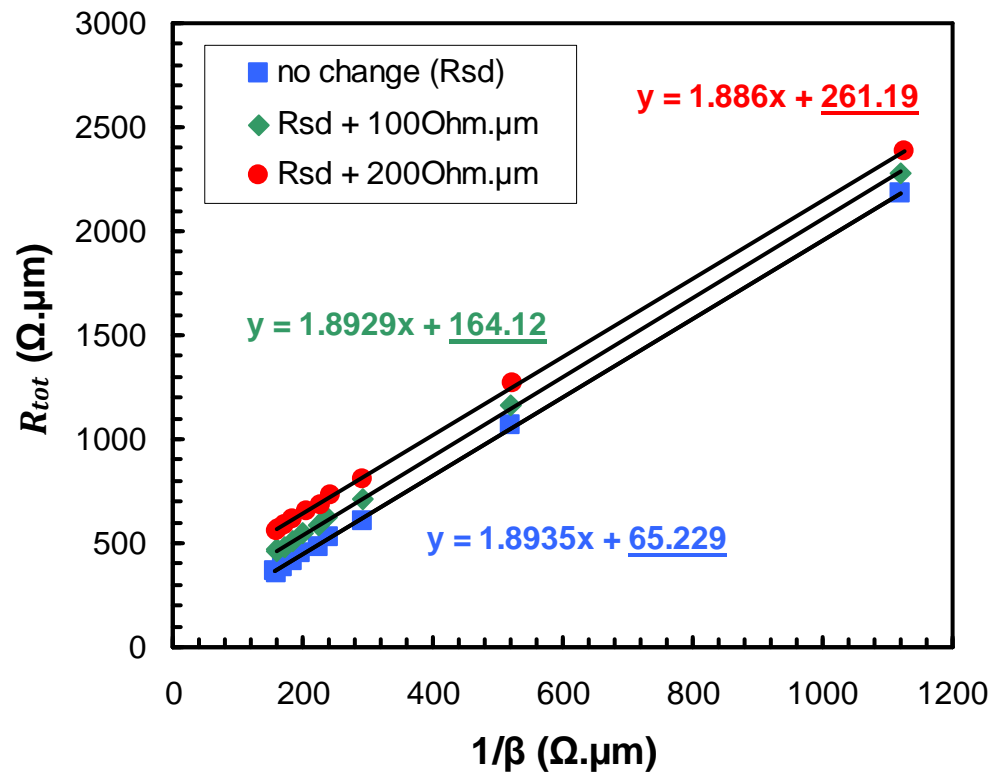
- Results are consistent with the Y-fuction extraction
- Accuracy is improved !

$R_{sd} (\Omega \cdot \mu m)$	$R_{tot}(1/\beta)$	$\Theta(\beta)$
nMOS bulk	$110 \pm 3$	$119 \pm 10$
pMOS bulk	$170 \pm 5$	$155 \pm 15$
nMOS FDSOI	$97 \pm 5$	$126 \pm 34$
pMOS FDSOI	$156 \pm 5$	$208 \pm 50$

High dispersion  
using the Y-  
function technique

# The new technique: accuracy

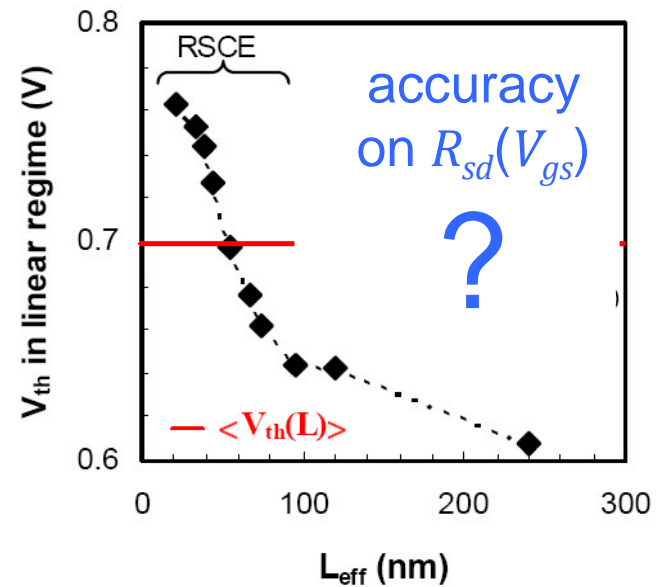
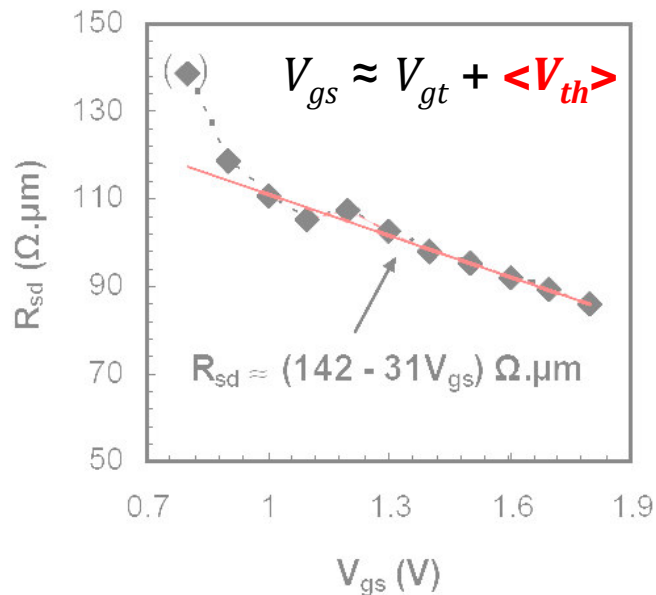
- Extracted values of  $R_{sd}$  follow the change if an additional resistance  $\Delta R_{sd}$  is added



# The new technique: discussion

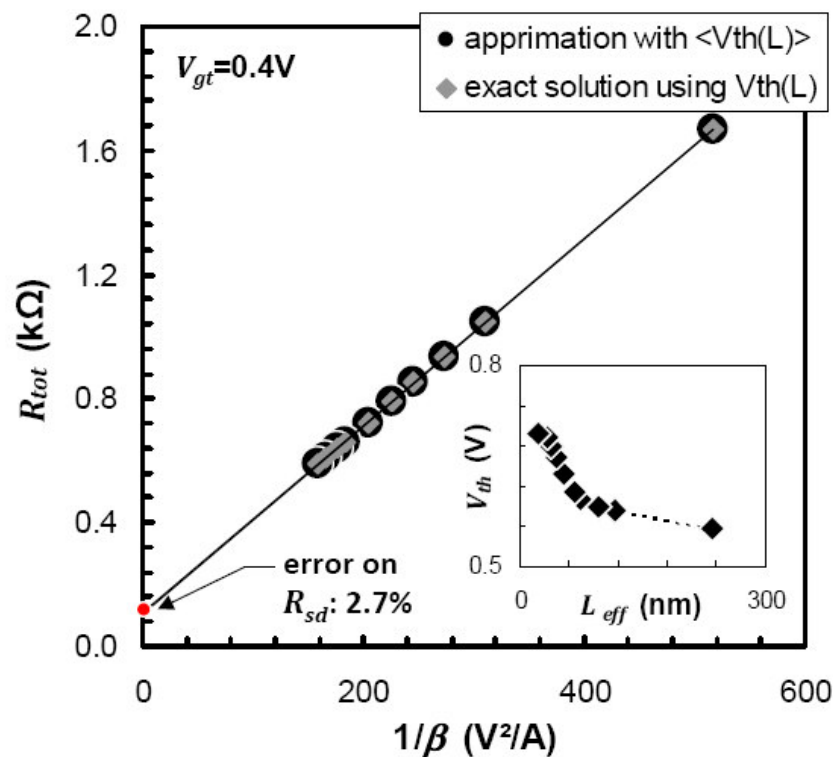
- $V_{th}$  may change as a function of  $L$ 
  - short channel effects (SCE) and S/D halos (RSCE)

$$R_{tot} = R_{ch}(V_{gt}) + R_{sd}(V_{gs})$$



# The new technique: discussion

- Is the  $V_{gs} = V_{gt} + \langle V_{th} \rangle$  approximation still valid for bulk devices ? **YES**

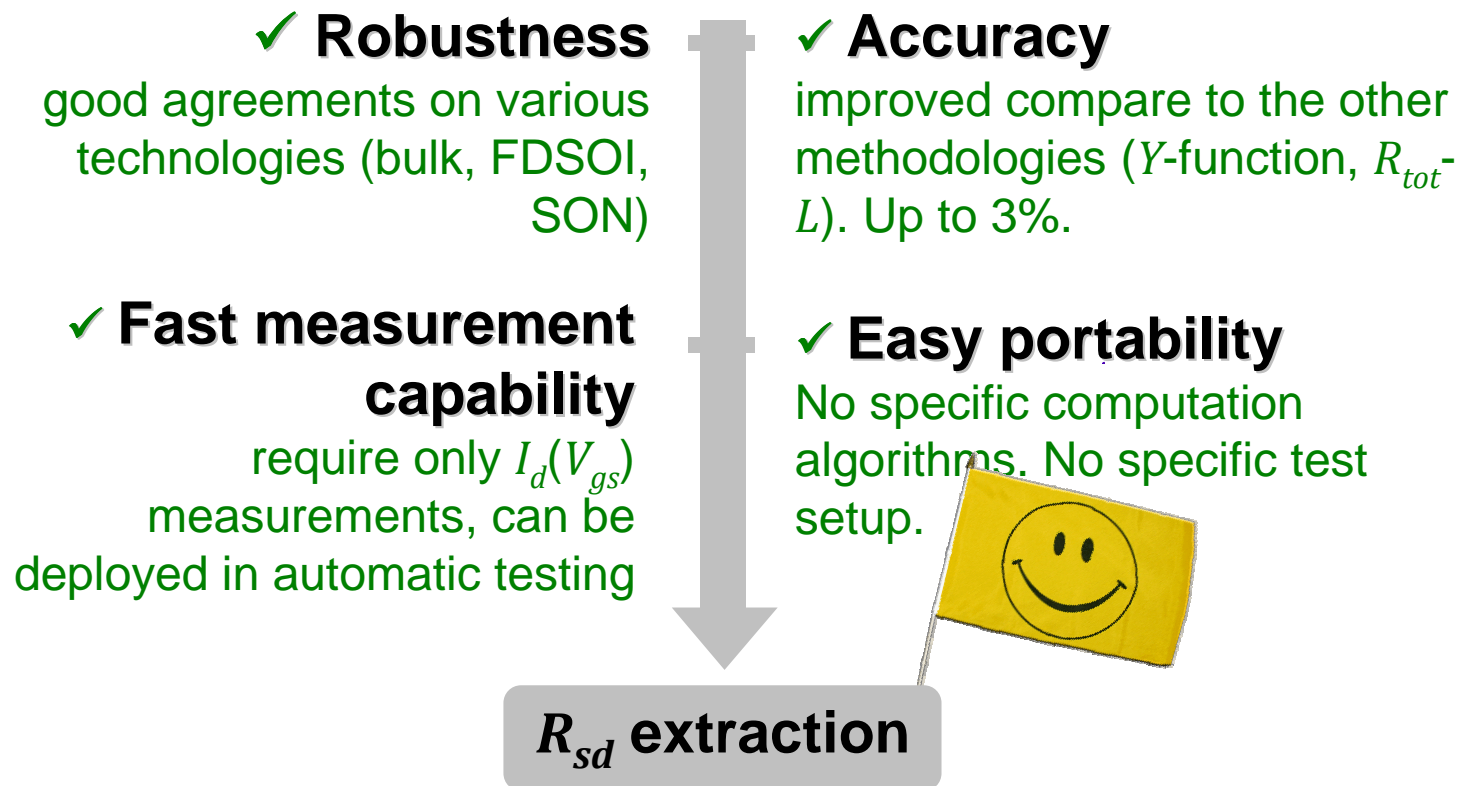


■  $\langle V_{th}(L) \rangle$  approximation still enable extraction within a 3% accuracy



# Conclusion

## ● Is the $R_{tot}-\beta$ suitable to an industrial context ?



# References

- [1] D. Fleury *et al.*, *ICMTS*, 2008
- [2] G. Ghibaudo *et al.*, *Electronics Letters*, 24, 9, 1988
- [3] M. F. Hamer, *IEE Proceedings*, 133, 2, 1986
- [4] Y. Taur *et al.*, *EDL*, 13, 5, 1992
- [5] K. M. Cao *et al.*, *IEDM*, 1999
- [6] F. Andrieu *et al.*, *EDL*, 26, 10, 2005
- [7] A. Cros *et al.*, *IEDM*, 2006
- [8] S.-D. Kim *et al.*, *TED*, 49, 3, 2002

**Thank you for your attention !**