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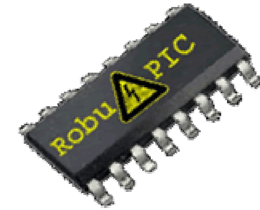

Electro-thermal EKV-based DMOS model

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Speaker : R. Gillon, AMI Semiconductor Belgium

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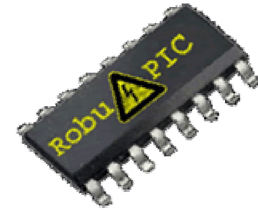
Outline



- Modelling self-heating – Why ?
- Modeling self-heating – How ?
- Model Assumptions
- Temperature Uniformity
- Mobility Effects
- Thermal Impedance

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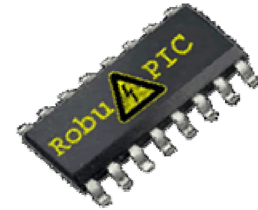
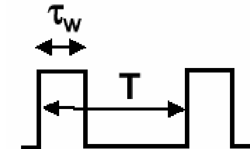
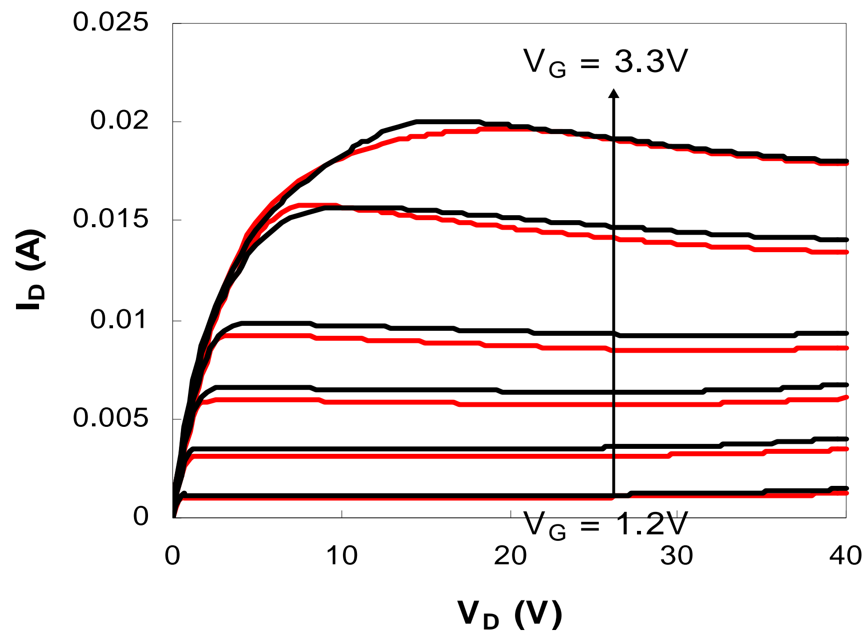
Model self-heating – Why ?



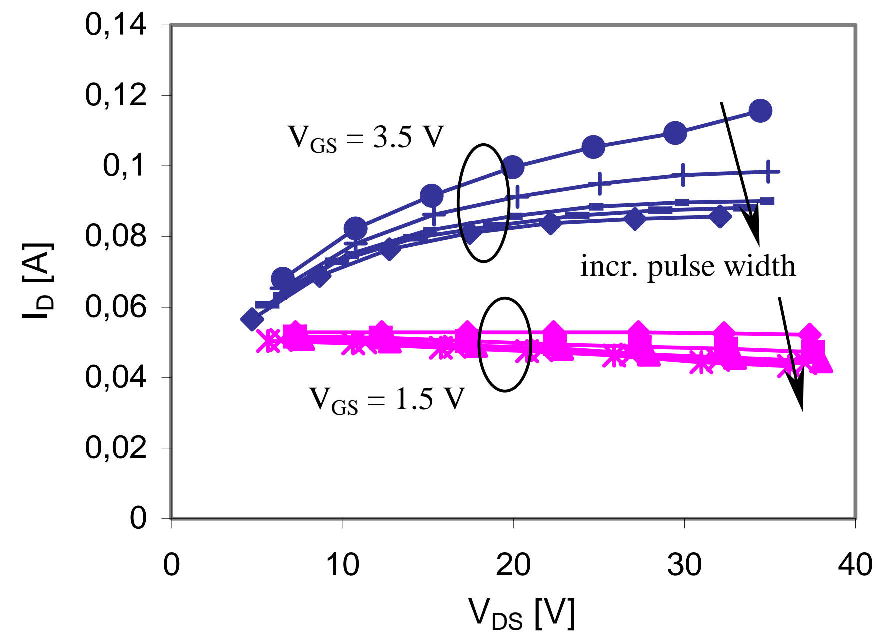
Because it is present…



Static Measurements



Pulsed Measurements



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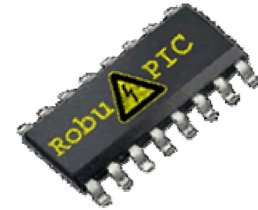
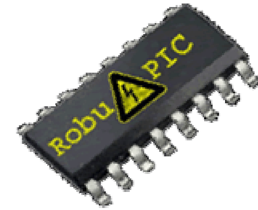
Model self-heating – Why ?



- Advances in device integration and process technology result in higher power densities on-chip
  - Higher temperature rises are needed to evacuate the heat
  - Self-heating becomes also apparent on smaller devices
- Applications require higher operating temperatures
  - High temperature operation involves a reliability risk (BTI, EM)
  - Need to design with lower temperature margins
- Applications require higher chip robustness
  - Some failure modes in power drivers are related to excessive temperatures (energy capability – critical temperature)
  - Ability to predict TRise accurately allows to save area (= cost)

Model self-heating – How ?



- Addition of one thermal node for dynamic temp. rise
- The power balance yields the dynamic temp. rise
- Feedback of the dynamic temperature into mobility eqns

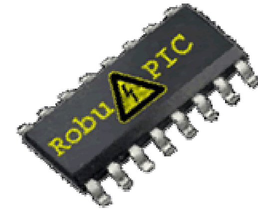
$$P_D = I_D \cdot (V_D - V_S) = R_{Th}(T) \cdot \Delta T + C_{Th} \frac{d\Delta T}{dt}$$

$$K_P = K_{PNom} \cdot \left(1 + \frac{\Delta T}{T_{Nom}}\right)^{-\kappa}$$

$$R_{Drift} = R_{DriftNom} \cdot \left(1 + \alpha_{Drift} \frac{\Delta T}{T_{Nom}}\right)$$

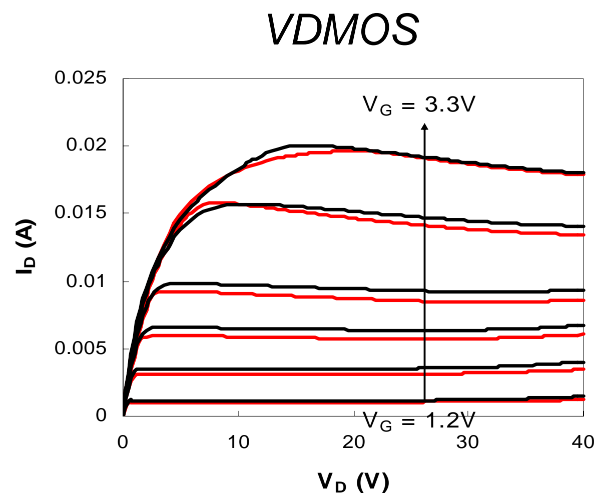
$$\kappa = \frac{2.7}{|V_g - V_s| + 0.1}$$

Model Assumptions

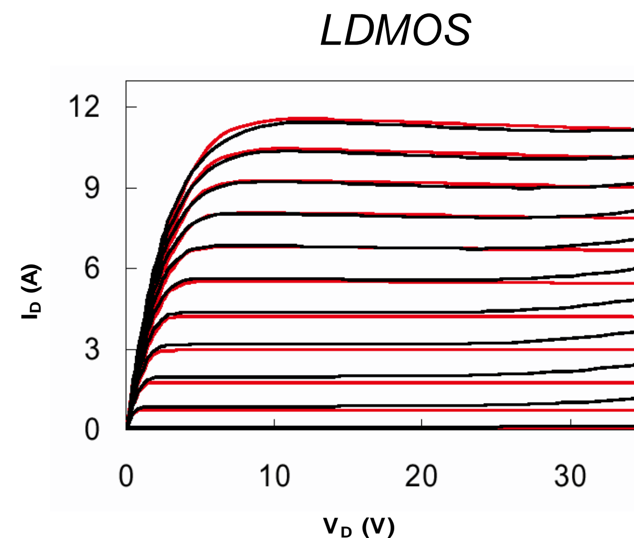


- The DMOS has a uniform temperature = $T_{Amb} + \Delta T$
- Mobility effects dominate the self-heating behaviour
- Self-heating effects on V_{th} are neglected
- Independent temperature behaviour of K_p and R_{drift}

VDMOS



LDMOS



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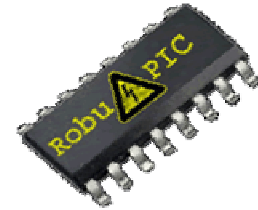
VDMOS Cross-section



Drain
Body
Source
Gate
Sinker
Drift region
Channel
Buried Layer
Substrate
Mirroring plane

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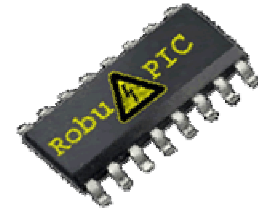
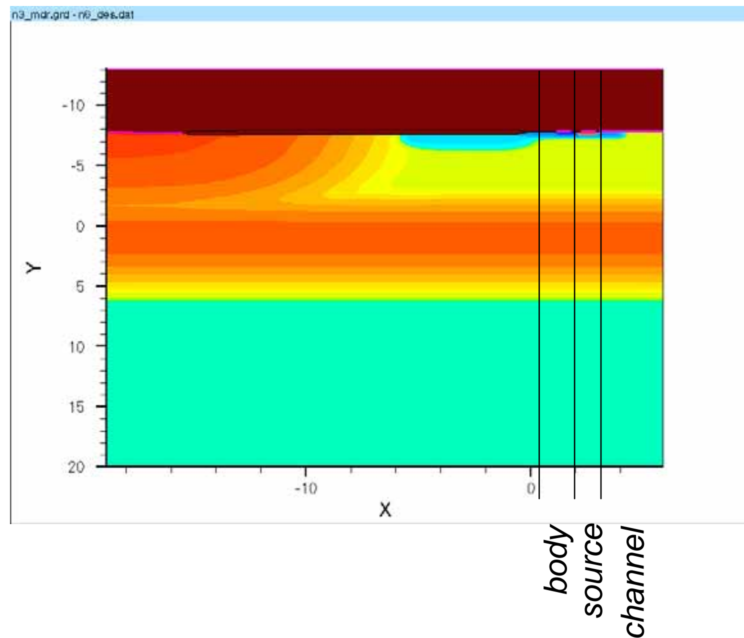
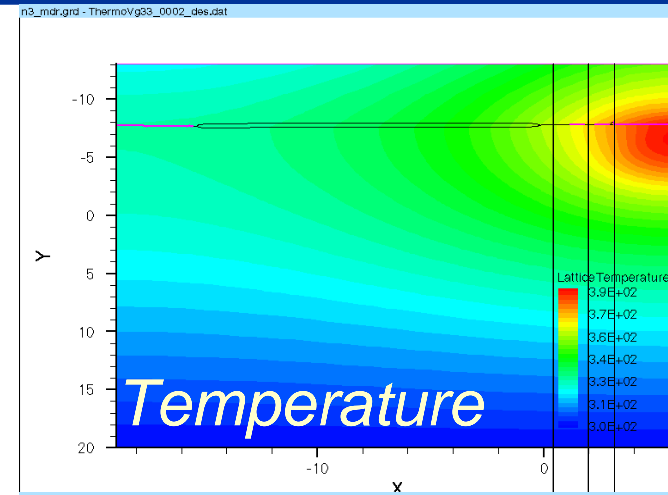
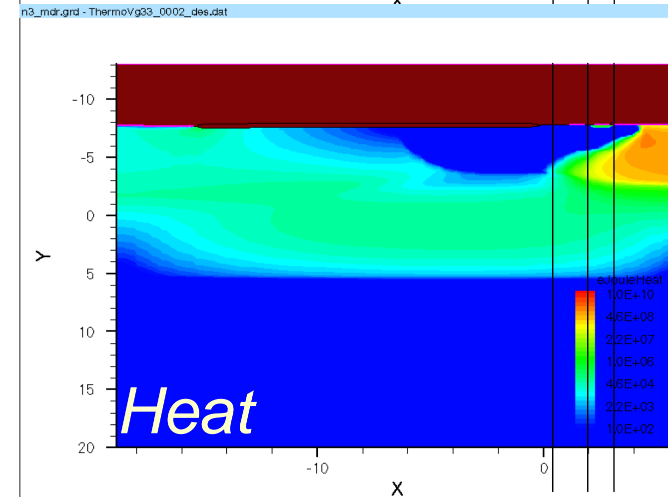
Temperature Uniformity



- TRise = 90C
- Variation in channel < 10C







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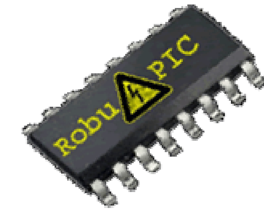
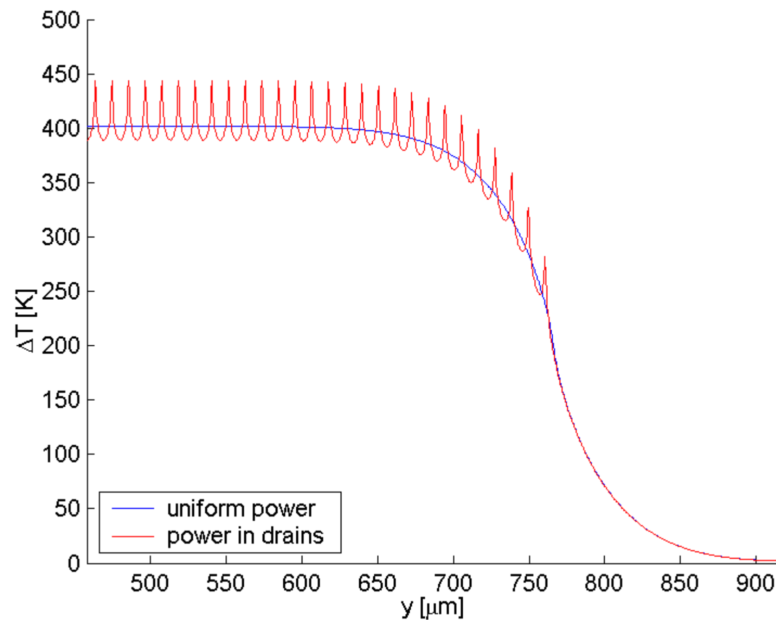
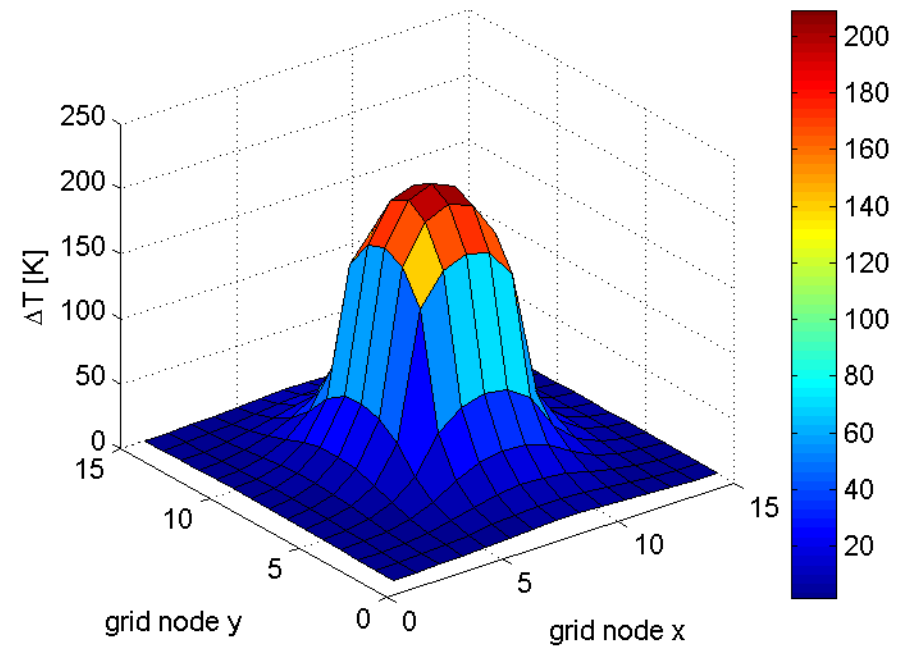
Temperature Uniformity



- ✓ Verified inside the channel
- What about multiple channels and large widths ?





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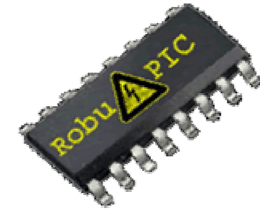
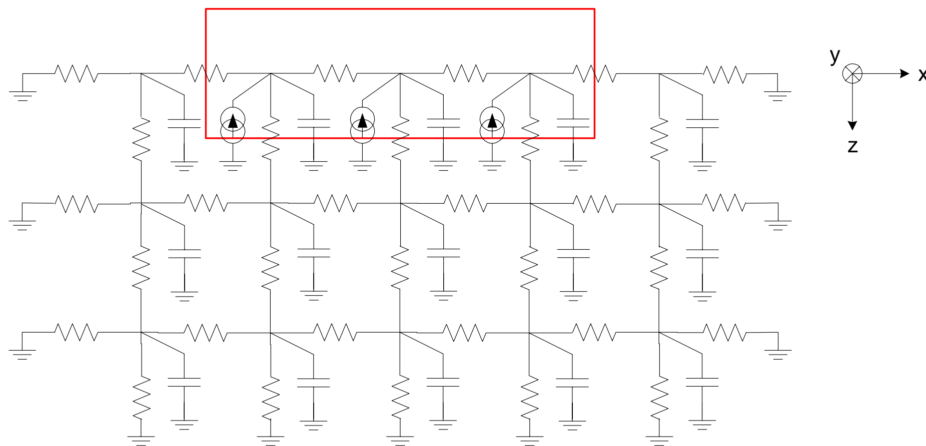
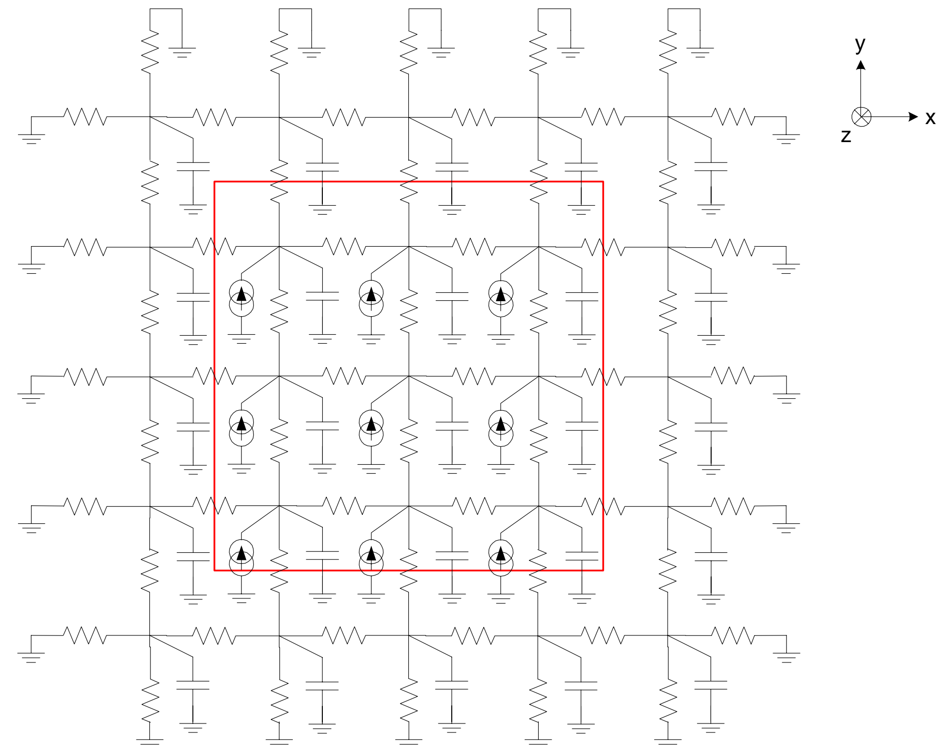
Spatial Discretization

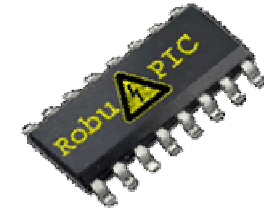


- Discretized electrical and thermal networks
  - DMOS cells : typically 5x5, with ~ 90um x 90um per cell
  - Thermal impedances (temp. dependant)



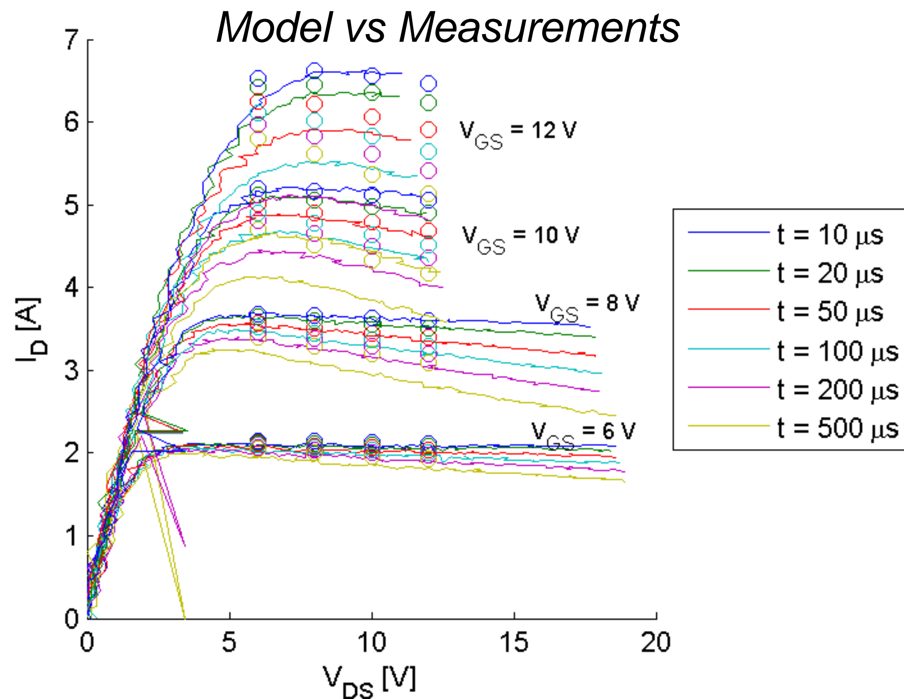


Spatial Discretization

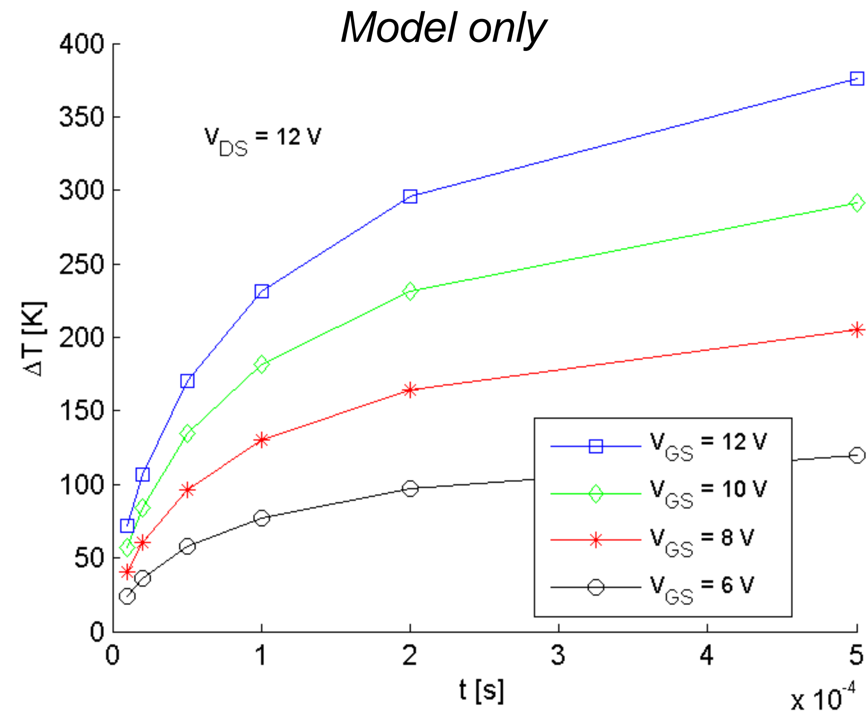


- <u>Validation</u> :
  - On-wafer pulsed current measurements on a large driver
  - DMOS model not EKV, but same principle

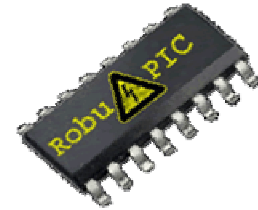
Model vs Measurements



Model only



Mobility Effects Dominate



- Self-heating occurs at moderate to high VD's
- In those conditions, the drift region FET controls I_d
- Most dissipation and highest temperatures occur in the drift region

⇒Limited influence of thermally induced V_{th} shifts

- As V_{th} decreases with temperature, at low V_g self-heating creates a positive feedback
  ⇒ risks of non-convergence
- Big drivers spend most of their time in on-state or off-state and make relatively short transition in regions where V_{th} effects are important

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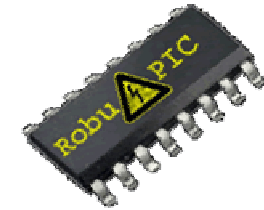
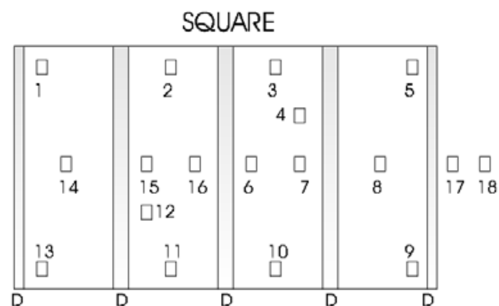
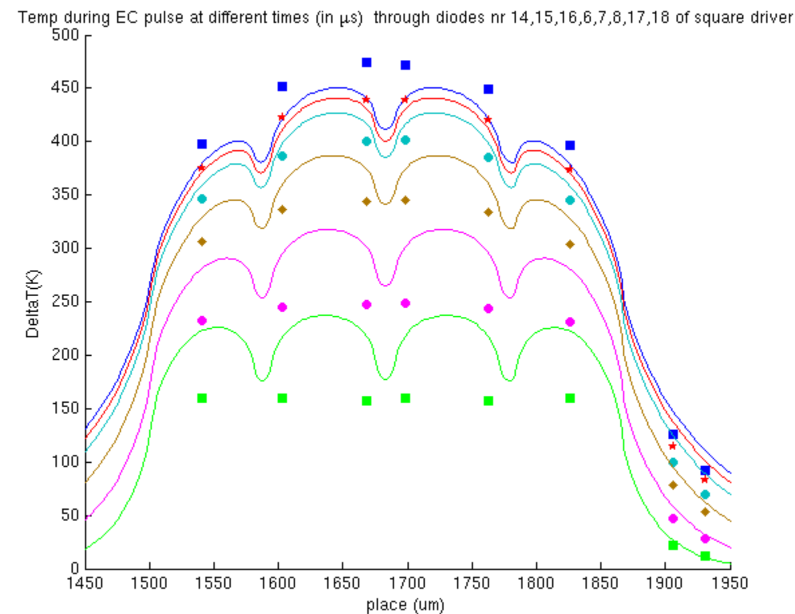
Thermal impedance



- Accuracy only if thermal impedances are correct
- Using formula's & techniques from Rinaldi et al.
- Experimental validation using temperature sensors





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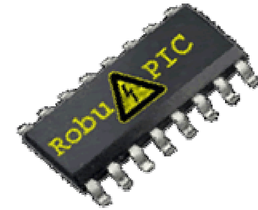
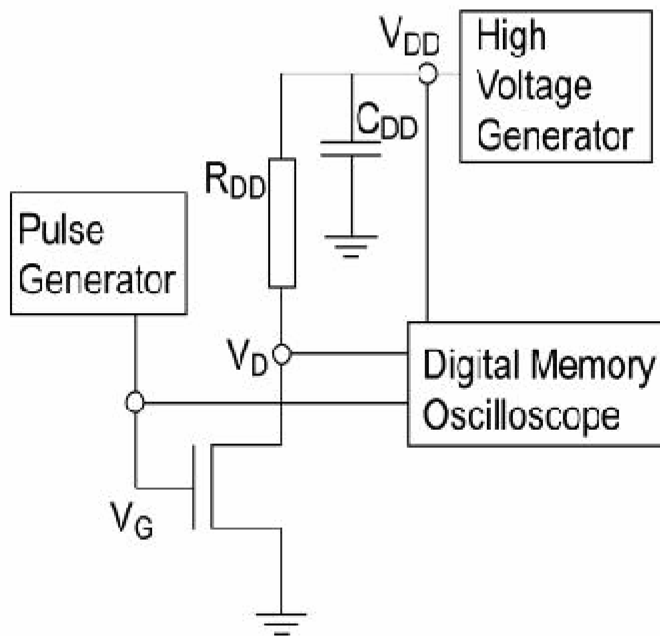
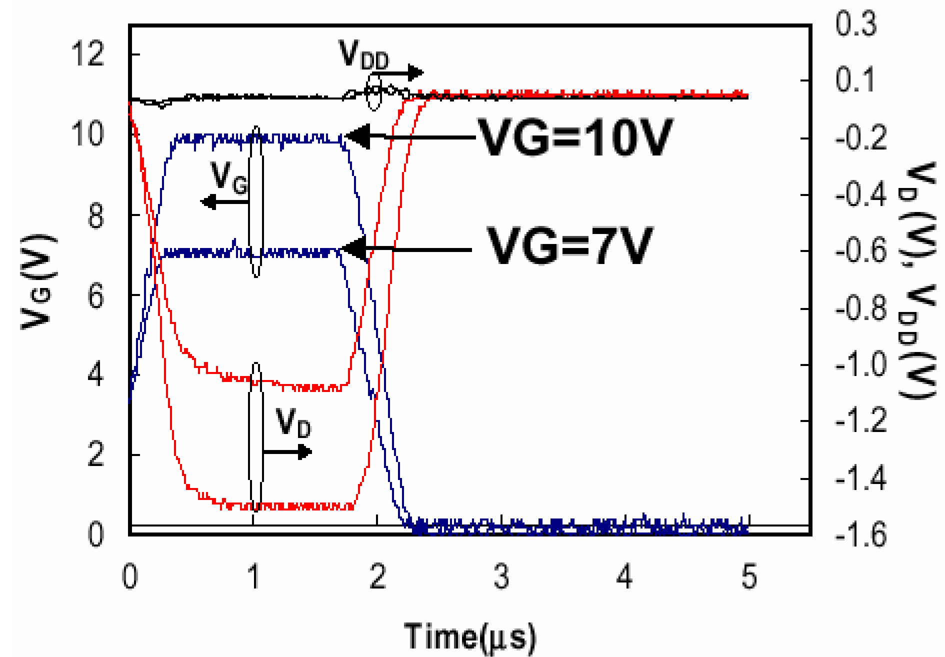
Thermal Impedance

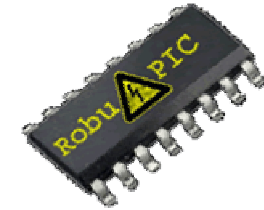


- Extraction method (Anghel et al., IEDM ’01)

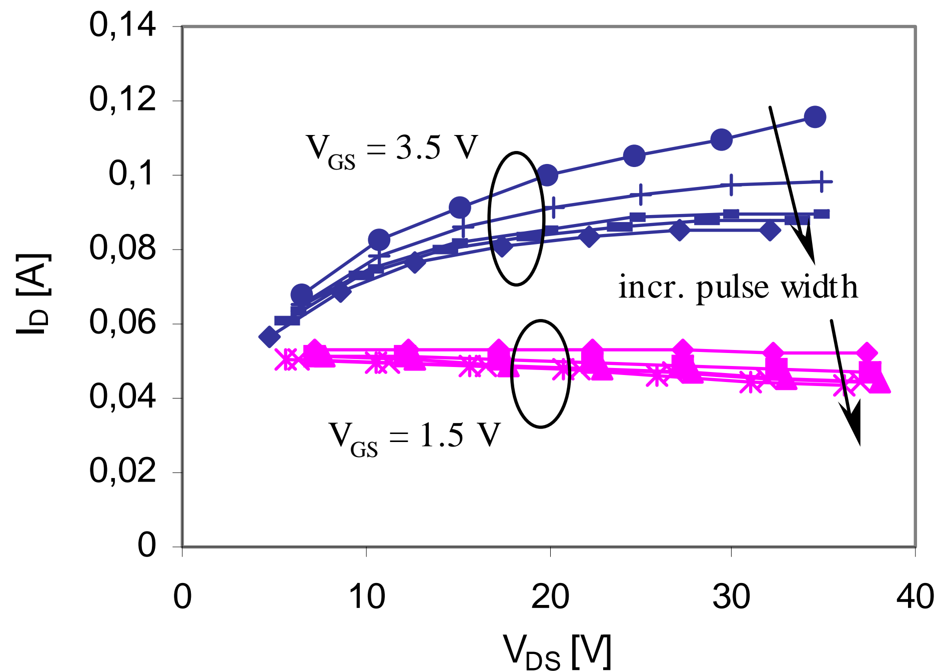


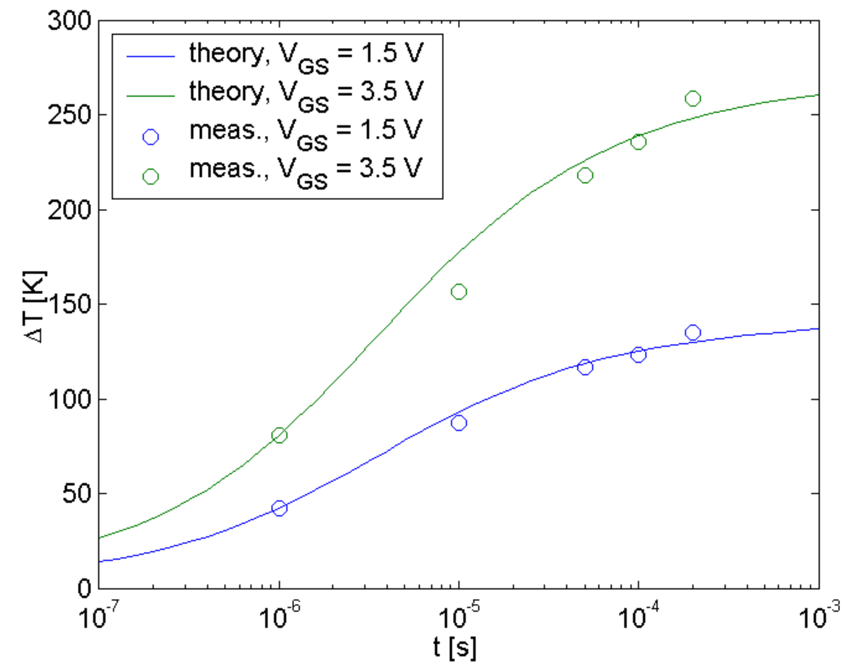


Thermal impedance



- Additional experimental validation using the empirical mobility reduction model : $I/I_0 = (T/T_0)^{-k}$





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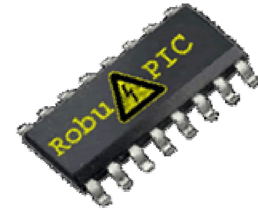
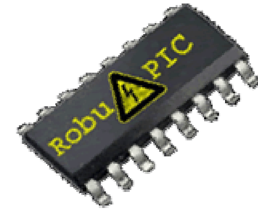
Conclusions



- Equations of the EKV DMOS self-heating model
- Reviewed the current assumptions / limitations
- Stressed the importance of thermal impedances
- Showed several experimental validations
- Discretization scheme to model large drivers

- Future activities :
  - Collect more experimental data to validate package models and thermal simulators (transistor – chip – package)
  - Check if Vth effect can be included

References



- C. Anghel et al., “New Method for Temperature-dependant Thermal Resistance and Capacitance Accurate Extraction in High-voltage DMOS transistors”, IEDM 2001
- B. Desoete et al., “A fast and flexible thermal simulation tool validated on smart power devices”, ISPSD 2005
- Allesandro et al, “SPICE Simulation of Electro-thermal Effects in New-generation Multicellular VDMOS Transistors”, MIEL 2002
- N.Rinaldi, “Thermal Analysis of Solid-state Devices and Circuits: an Analytical Approach”, in Solid-State vol.44, pp.1789-1798, 2000.
- Rinaldi et al., “Generalized Image Method With Application to the Thermal Modeling of Power Devices and Circuits”, IEEE Tran ED, Vol. 49, No. 4, April 2002
- Rinaldi et al., “On the Modeling of the Transient Thermal Behavior of Semiconductor Devices”, Vol. 48, No. 12, Dec 2001