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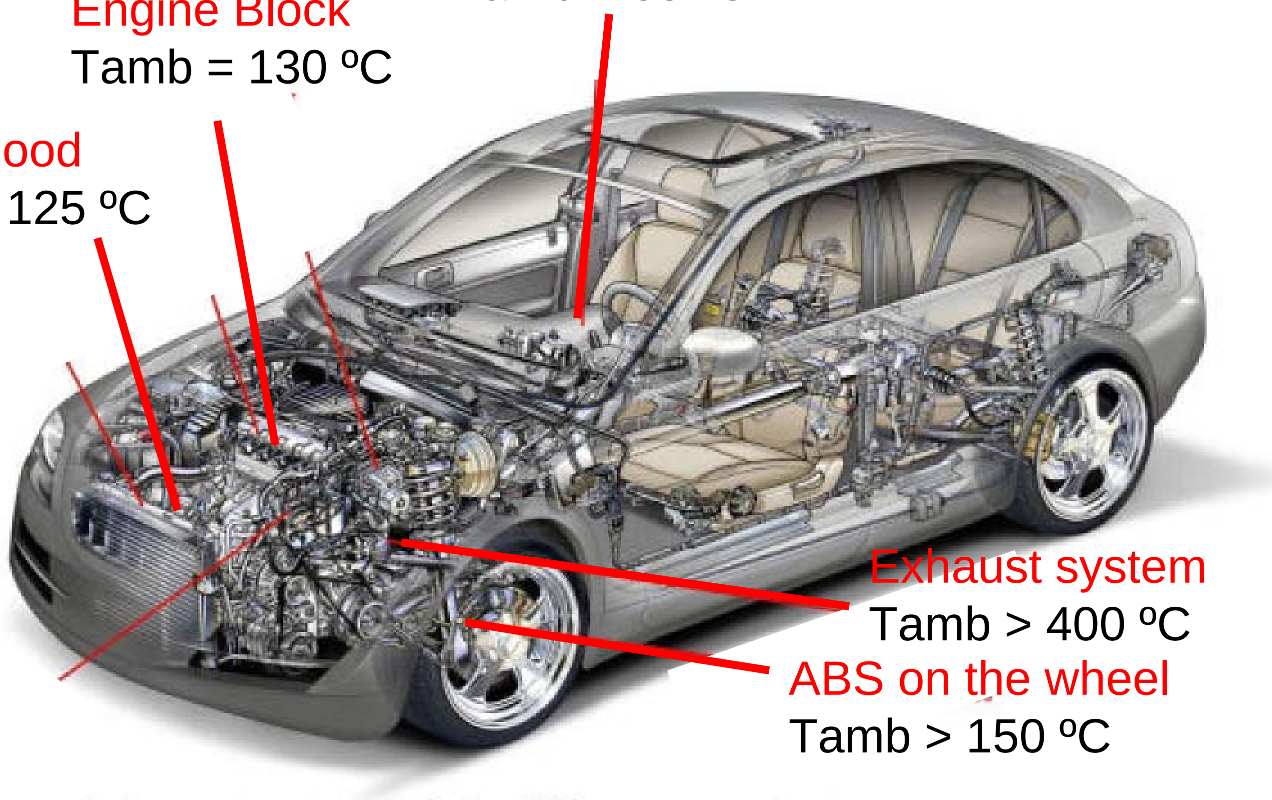
High Temperature (HT) Management Program at ON Semiconductor

Introduction

Push to higher junction temperature

1. Applications under the hood
   → Higher Tamb



Introduction

Push to higher junction temperature

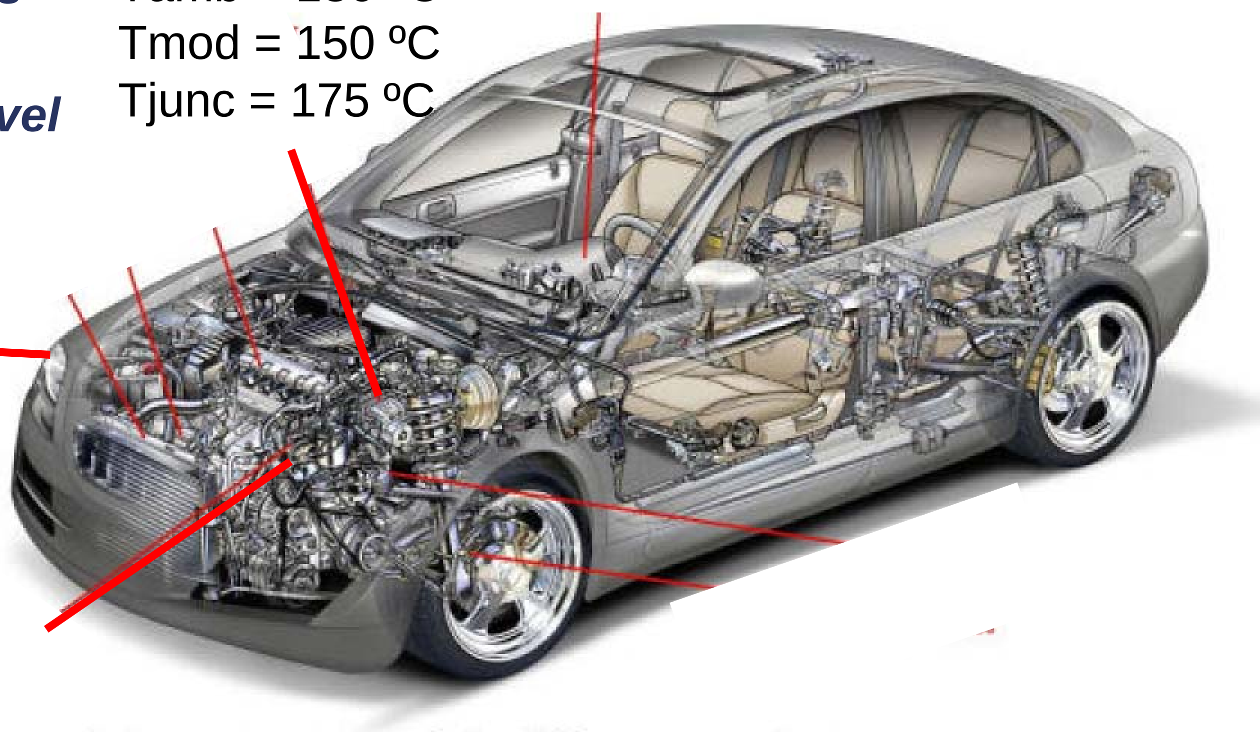
1. Applications under the hood
   → Higher Tamb

2. Mechatronic-modules
   → Higher Tmod

3. Higher integration level
   → Higher Tjunc

Alternator
Tamb = 130 ºC
Tmod = 150 ºC
Tjunc = 175 ºC

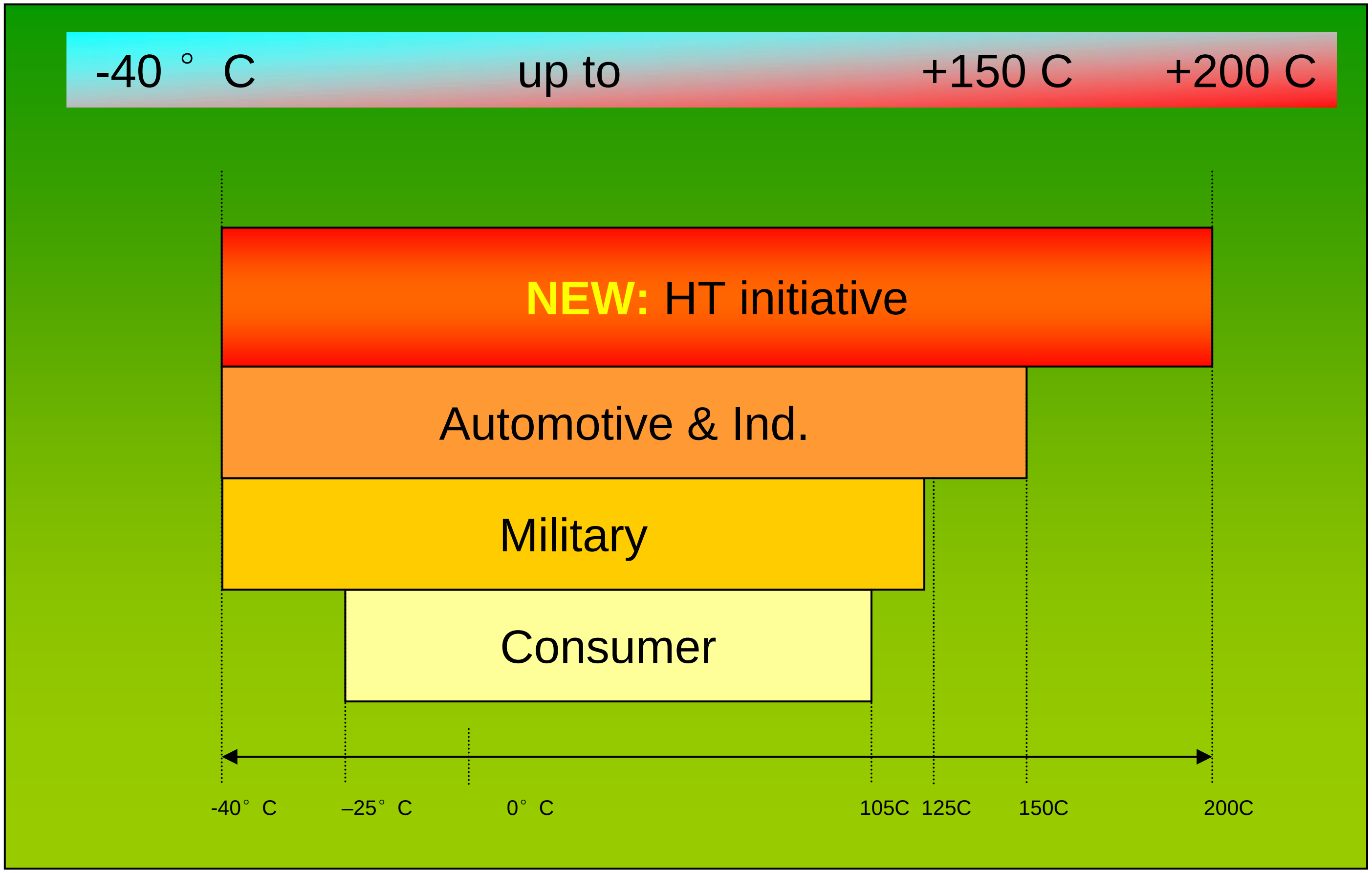
HID-lamp
Tamb = 125 ºC
Tmod = 135 ºC
Tjunc = 150 ºC



Oil-sensor
Tamb = 130 ºC
Tmod = 150 ºC
Tjunc = 165 ºC

High Temperature Program

HV techno at 200 C : I2T100 – I3T50 –I3T80



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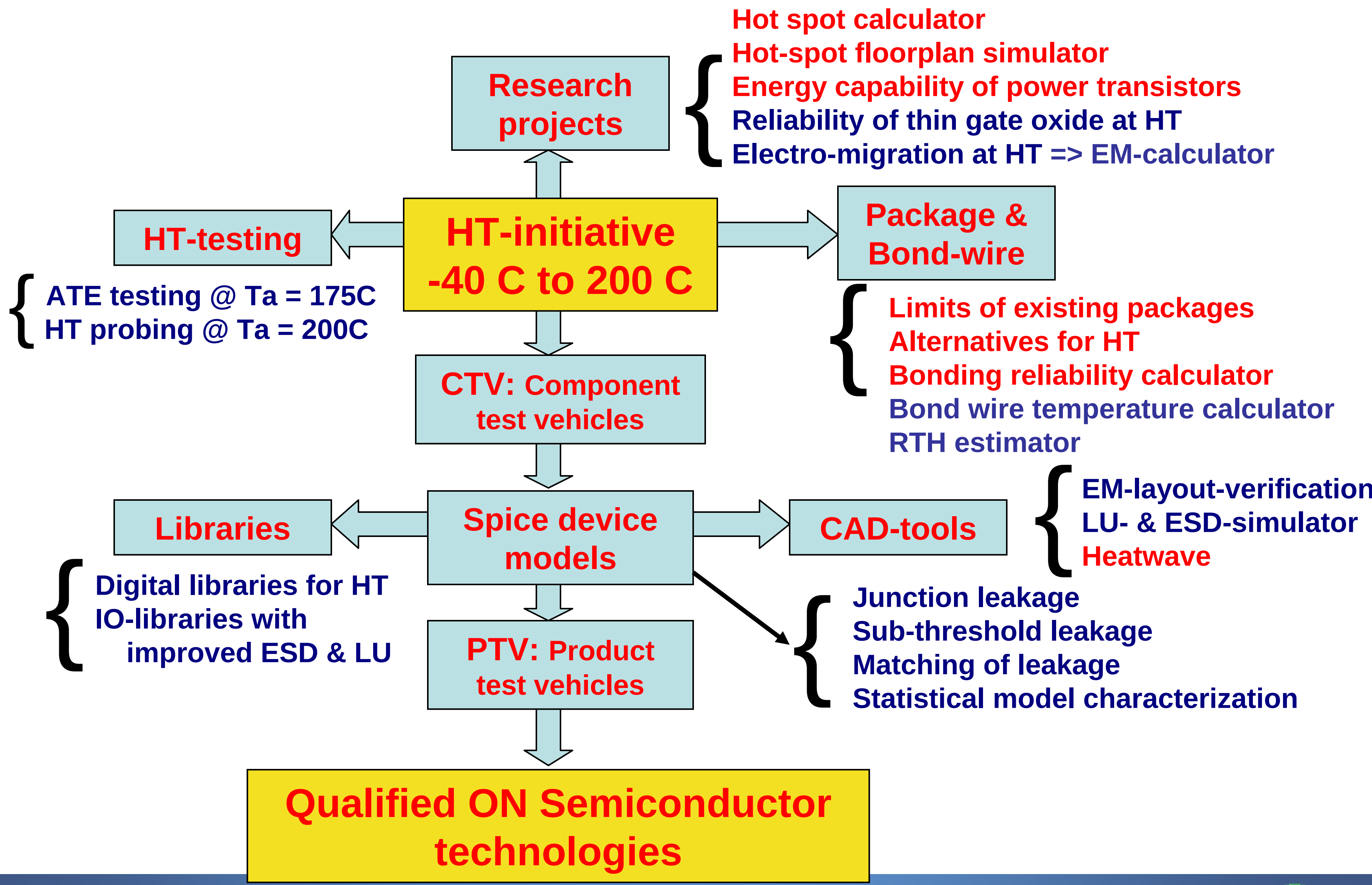

Thermal Profile

In operation, standby or power down (Biased)			Not in operation (Unbiased)	
Tambient (°C)	Tjunction (°C)	Cumulative duration (hours)	Tambient (°C)	Cumulative duration (hours)
+140°C to +150°C	+180°C	60	+140°C to +150°C	0
+130°C to +140°C	+170°C	340	+130°C to +140°C	0
+105°C to +130°C	+155°C	6000	+105°C to +130°C	0
+85°C to +105°C	+135°C	200	+85°C to +105°C	0
0°C to +85°C	+115°C	200	0°C to +85°C	141920
- 40°C to +150°C	+30°C	200	- 40°C to +150°C	0

Total operating	7000	Total non-operating	141920

Total lifetime (operating and non-operating):	17 YEARS
# Supply On/Off cycles	2000

Define a thermal profile at the start of a project,
to predict reliability for the full product life time!!

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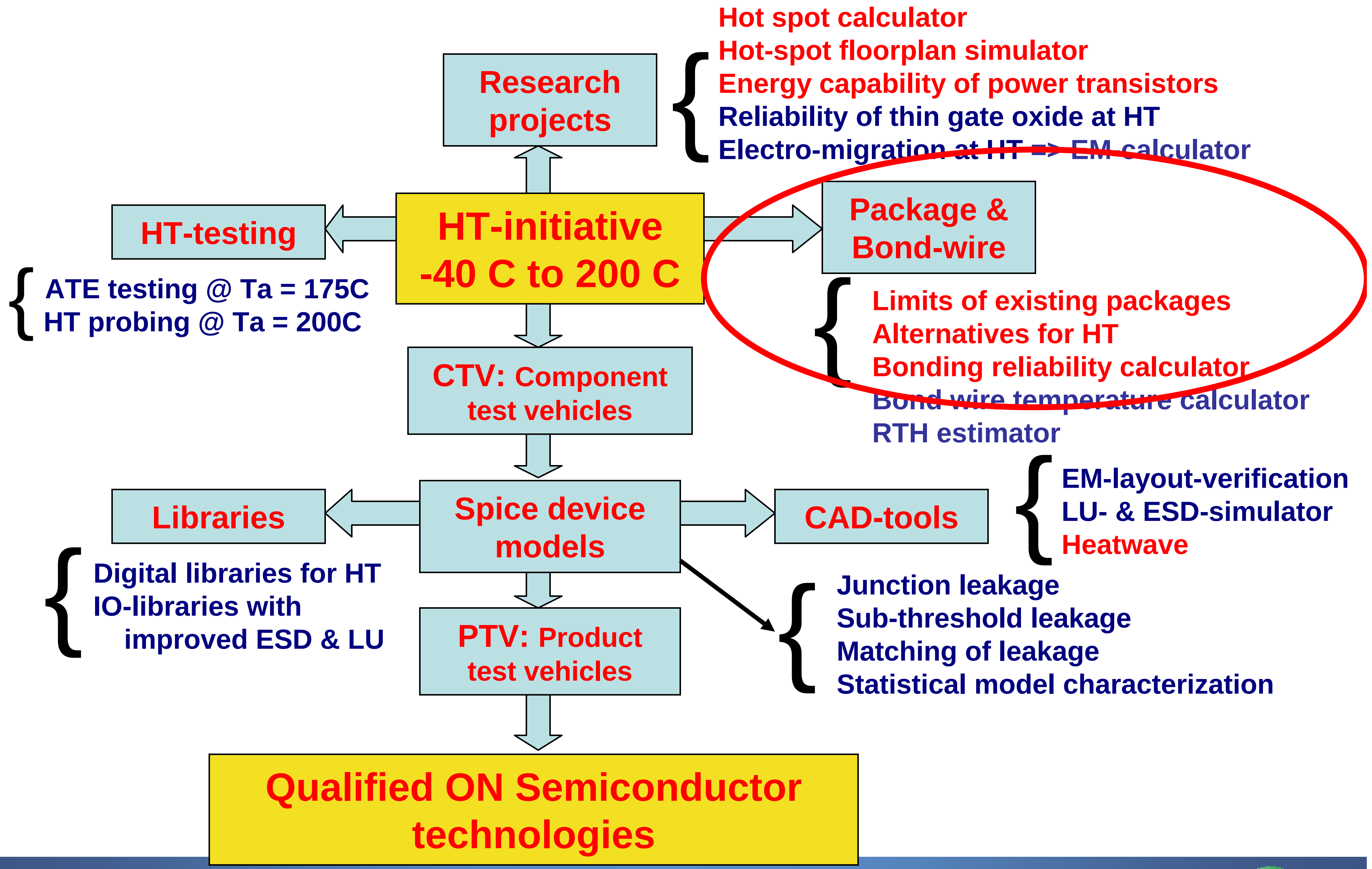
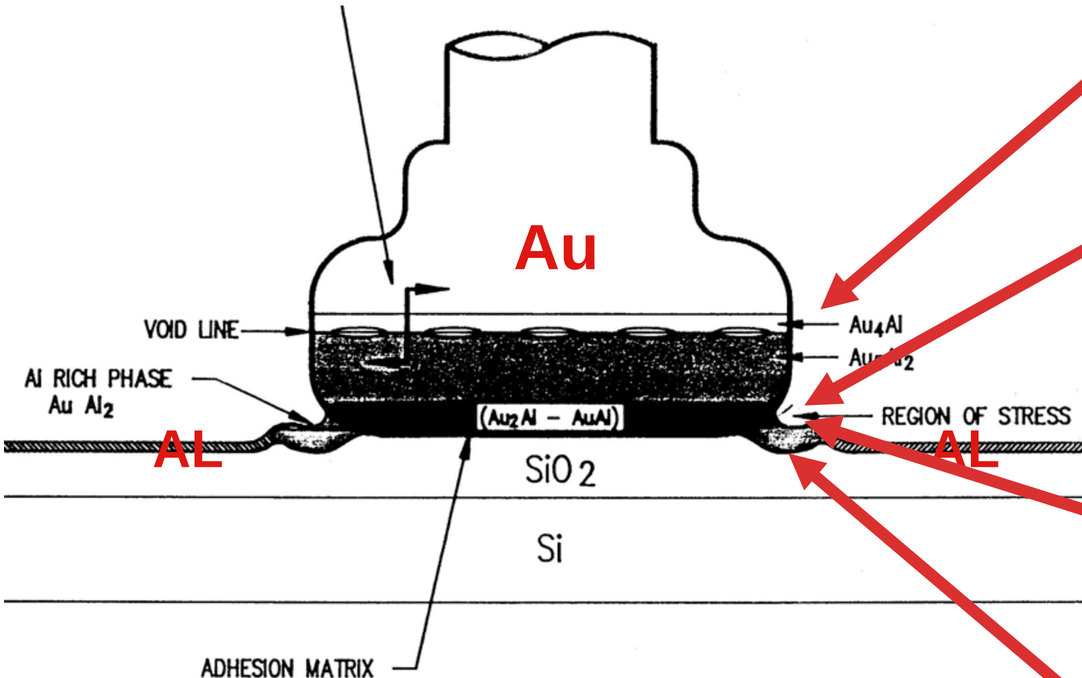


Bonding Reliability

Au/Al wire bond interconnect



All these 4 effects get worse with increasing temperature! (acceleration coeff. for 200 ° C is 6 times higher than for 150 ° C)

=> Leads to increased electrical resistance and finally bond wire disconnection

Failure modes;

1) Formation of brittle intermetallics

Mismatch between Thermal Coefficient of Au5Al2 and Au4Al

2) Kirkendal voiding due to un-equal inter-diffusion of 2 bond metals

Au diffuses more rapidly in Al than reverse

3) Voiding due to electro migration in bondpad metal

Only for negative currents through bond e.g. Ground-pin

4) Dry corrosion of intermetallics

With flame retardants (Br) in mold compound as catalyst.

Not for green mould compound

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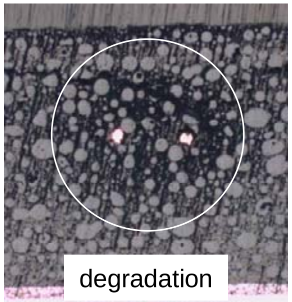
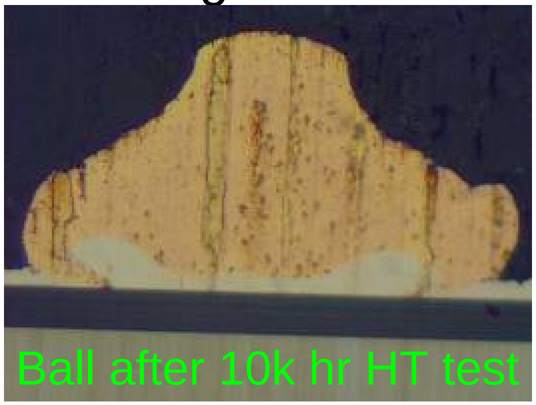
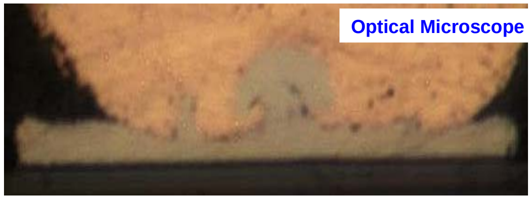
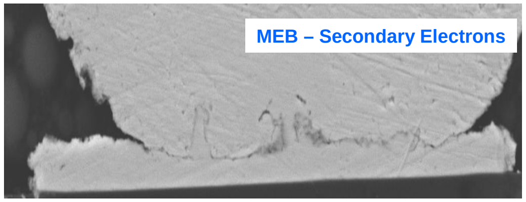
Limitations of Bondwires

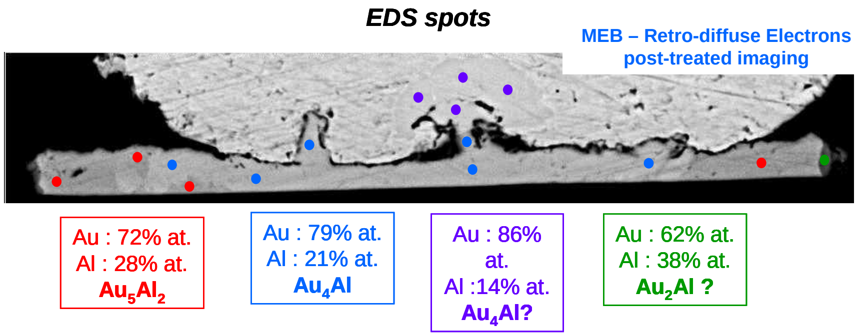


- Thermal limit (immediate destruction) :
  - Fusing temp. 660°C for Al,1063°C for Au
- Electro-chemical aging effects
  - Metal migration at the bonding interface (Kirkendale voiding)







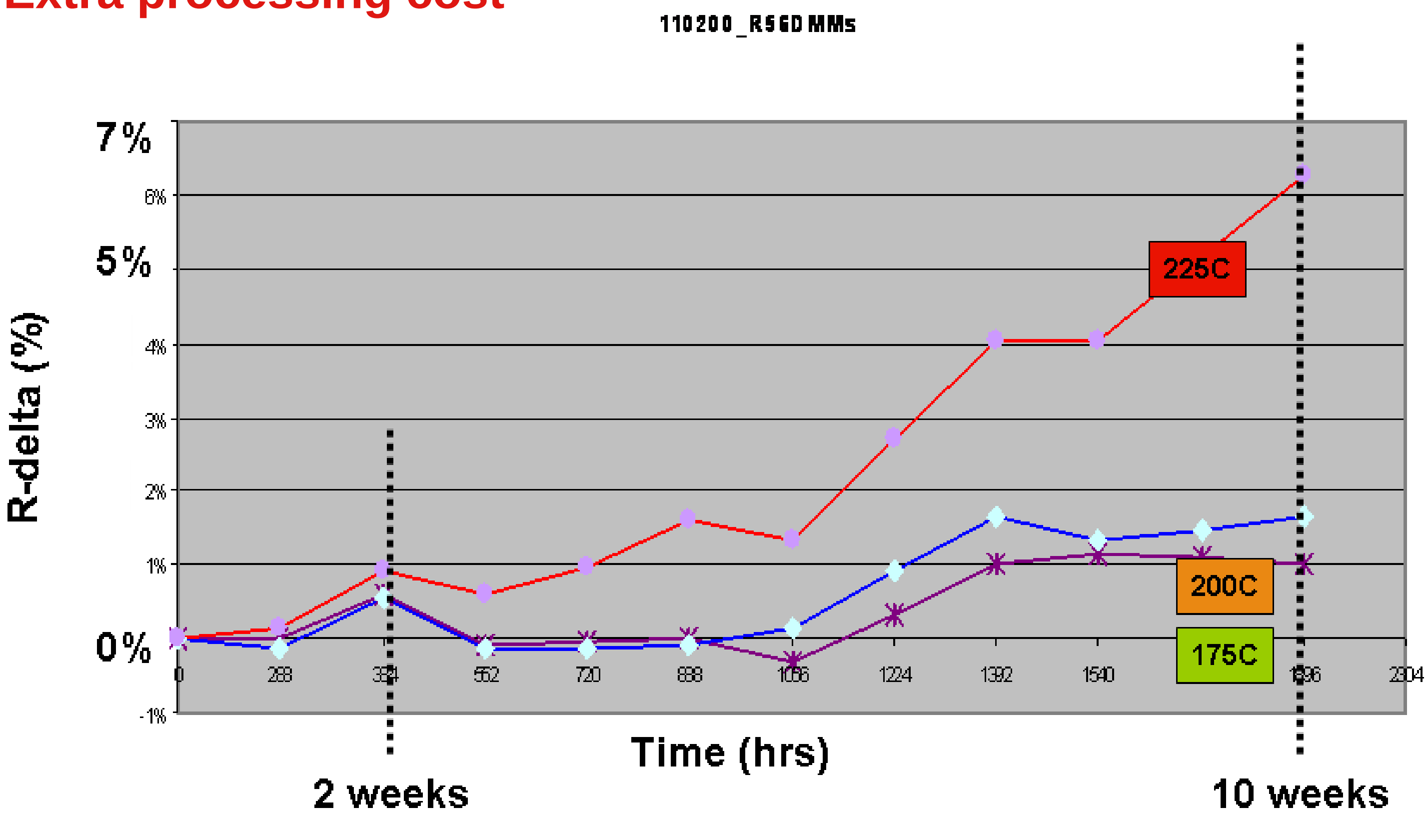


  - Corrosion
- Mechanical aging effects
  - In case of delamination of mold-die interface or presence of weak layers like poly-imide, more mechanical stress is exercised on bondwires which can break after several cycles

Bonding Reliability

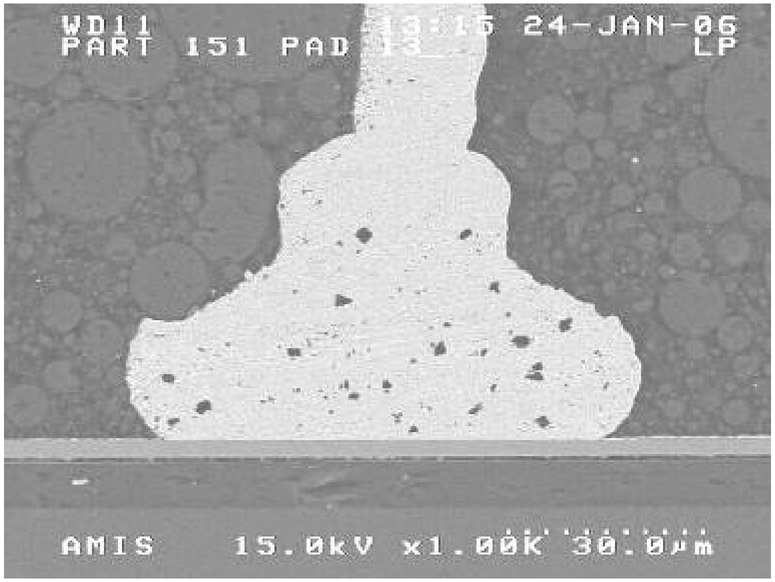
NiAu plated bond pads: OK for 200 C

- **1 mil Au-wire**
- **Extra processing cost**

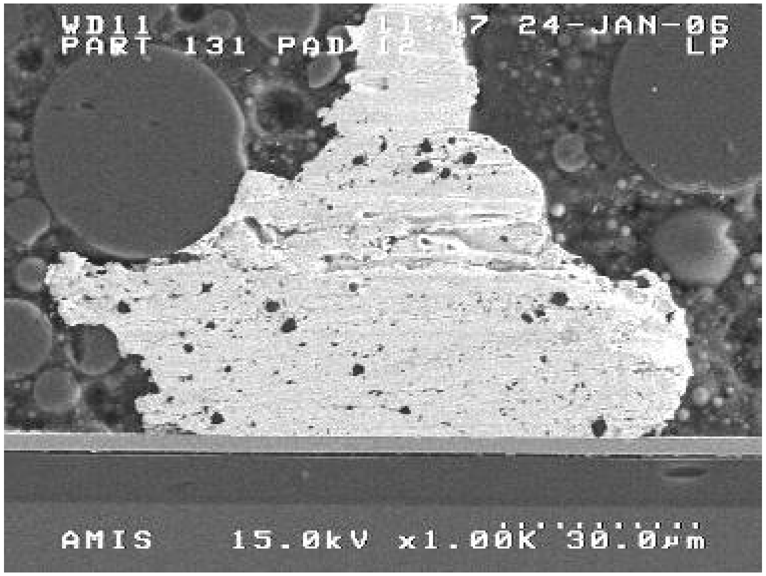


Decomposition of Green M/C

Molding compound decomposes at 225 C !



SEM photo of normal molding compound



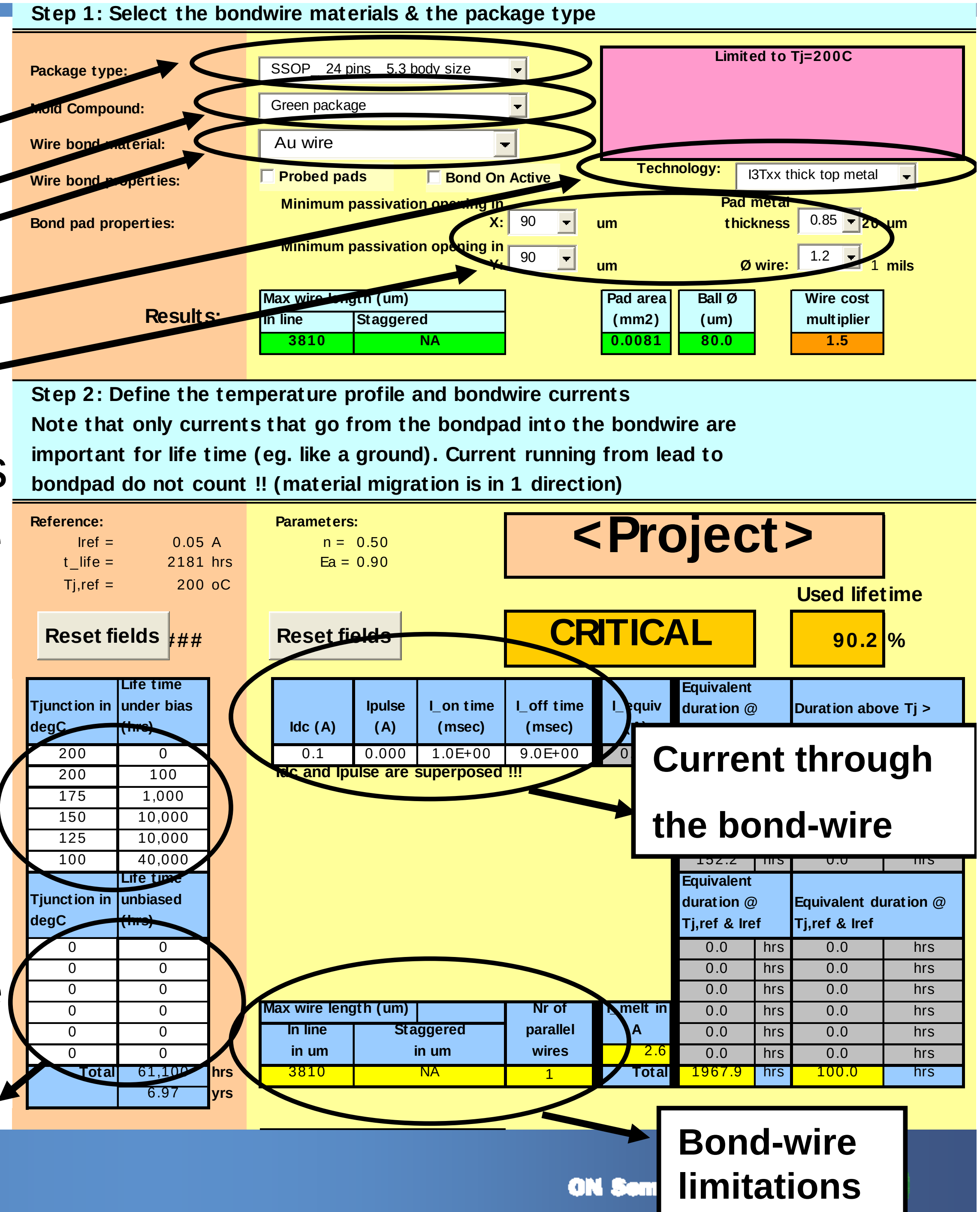
SEM photo of decomposed molding compound

Bonding Reliability Calculator

- Structural Inputs :
  - Package type
  - Mould compound
  - Wire type
  - IC technology
  - Bondpad-size
- Working Conditions
  - Temperature profile
  - Static and pulsed current levels
- Effects covered :
  - Corrosion and metal migration
  - Based on extensive experimental work

Under-Bias Thermal profile

Unbiased Thermal profile



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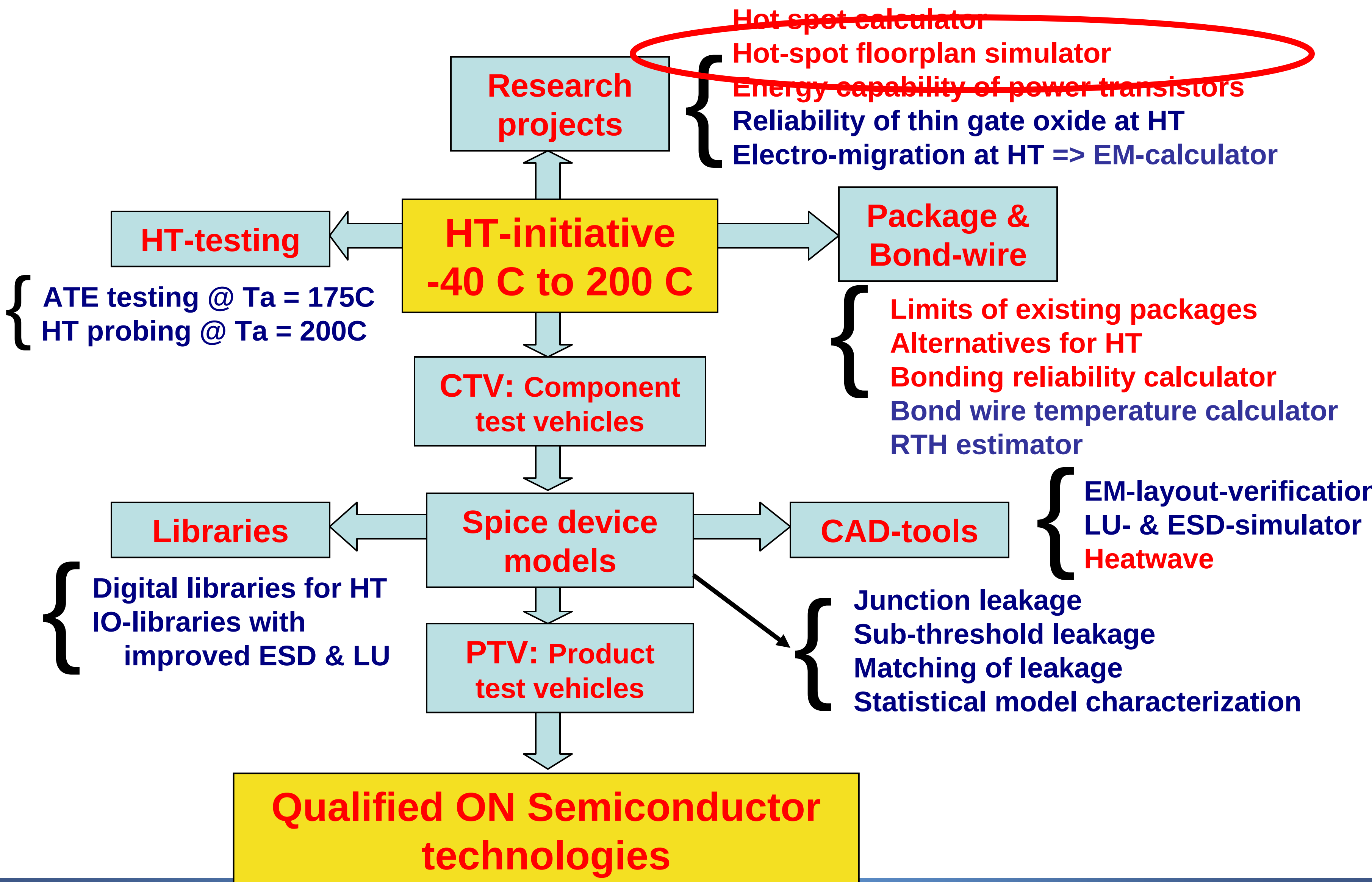
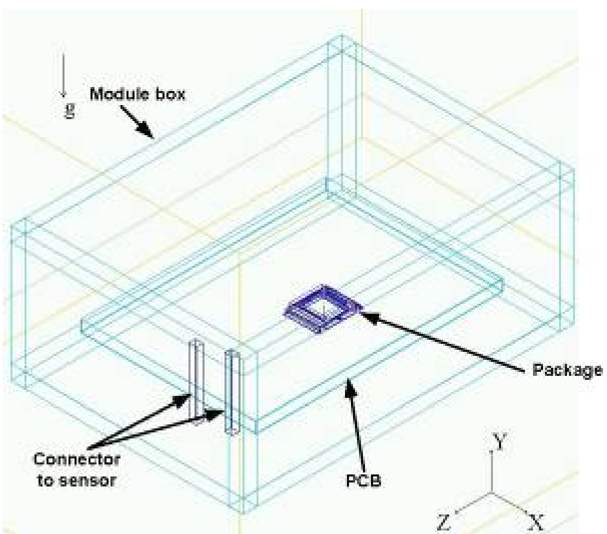


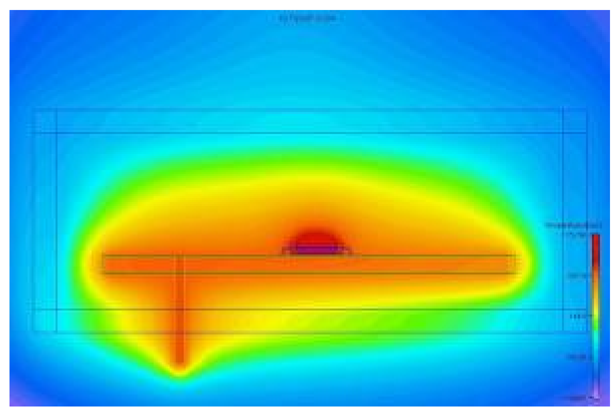
Thermal Simulators

- Junction-Temperature determines:
  - Bond-wire reliability
  - Electro-migration
  - Leakage + Matching
  - Latch-up + ESD
- Thermal simulators:
  - FloTherm + FloPack: commercial tool
    - Thermal simulations at application-level
  - Hot spot floor-plan simulator: ON Semiconductor tool
    - Developed in-house, based on Mathlab
    - Thermal transients at silicon-level
  - Heatwave: Co-development with Gradient
    - Links circuit-simulation and thermal simulation

Thermal Simulators

- Commercial simulator:
  - FloTherm + FloPack: Finite element simulator
    - Finite elements: module split up in small pieces to simulate the heat-flow and temperature. The precision is as accurate as the grid of the simulator.
    - FloPack create model of package.
  - Utilization:
    - Thermal simulations at application-level.





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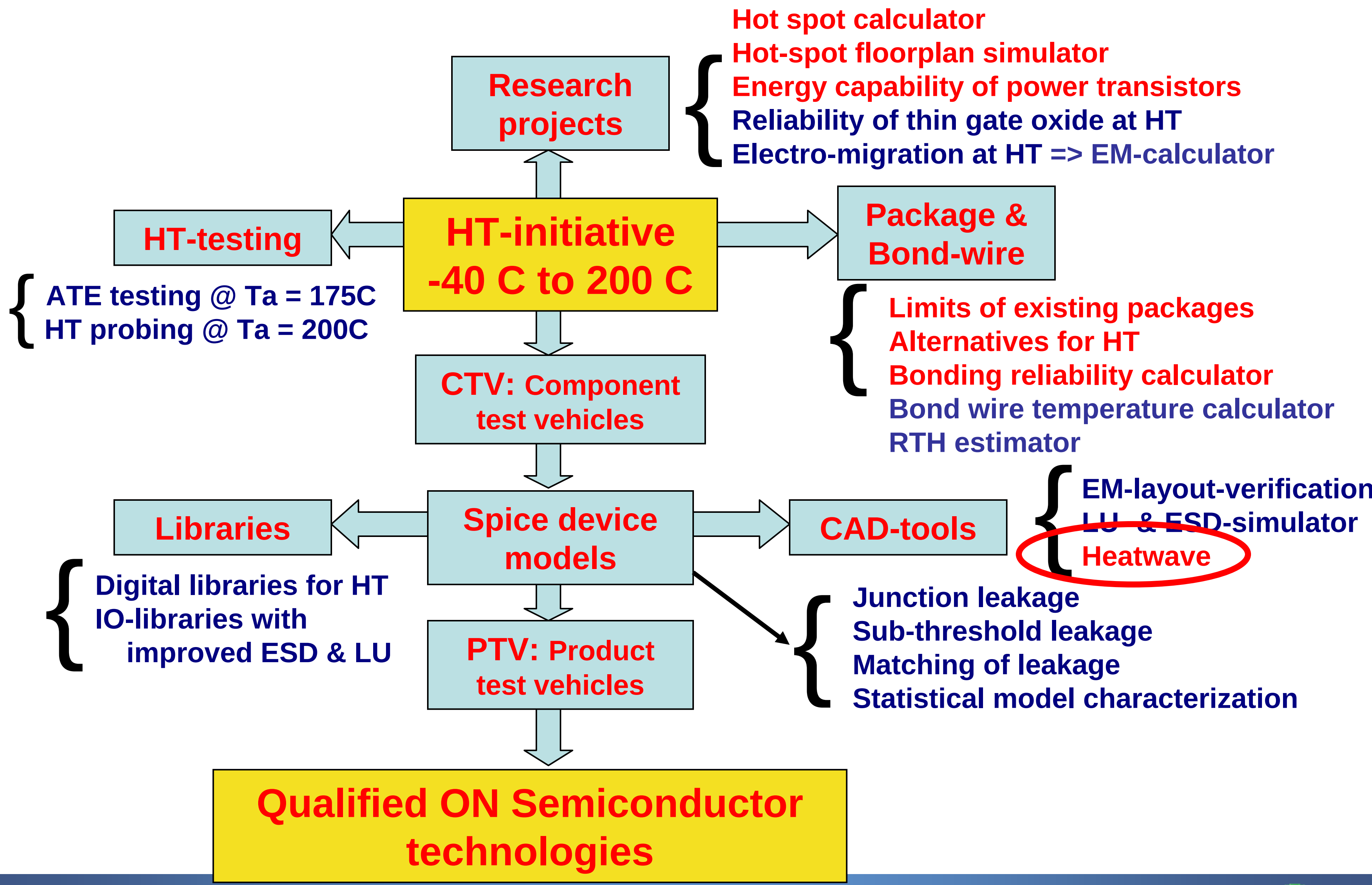
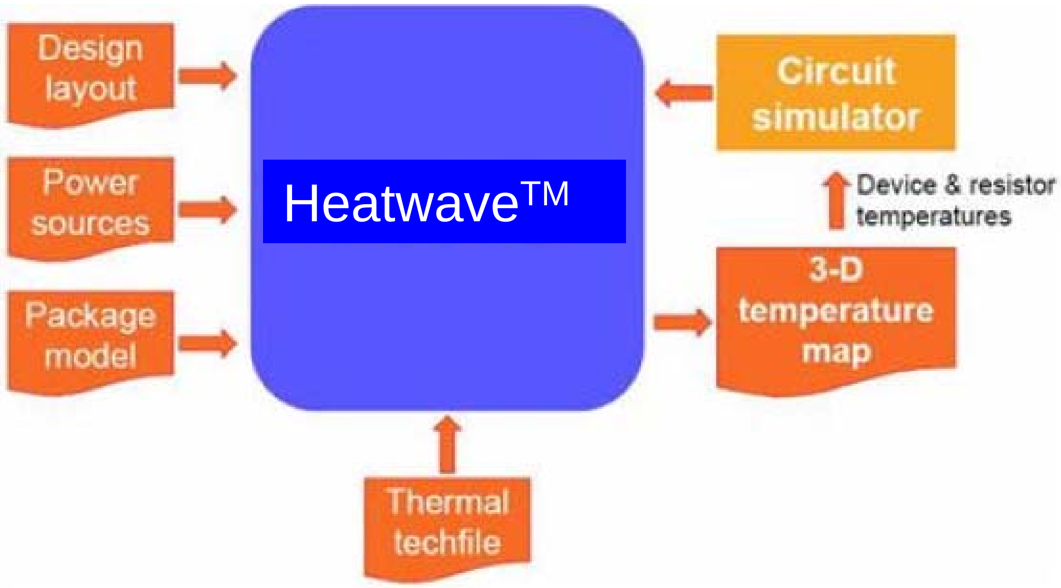


Electro- & Thermal-simulations

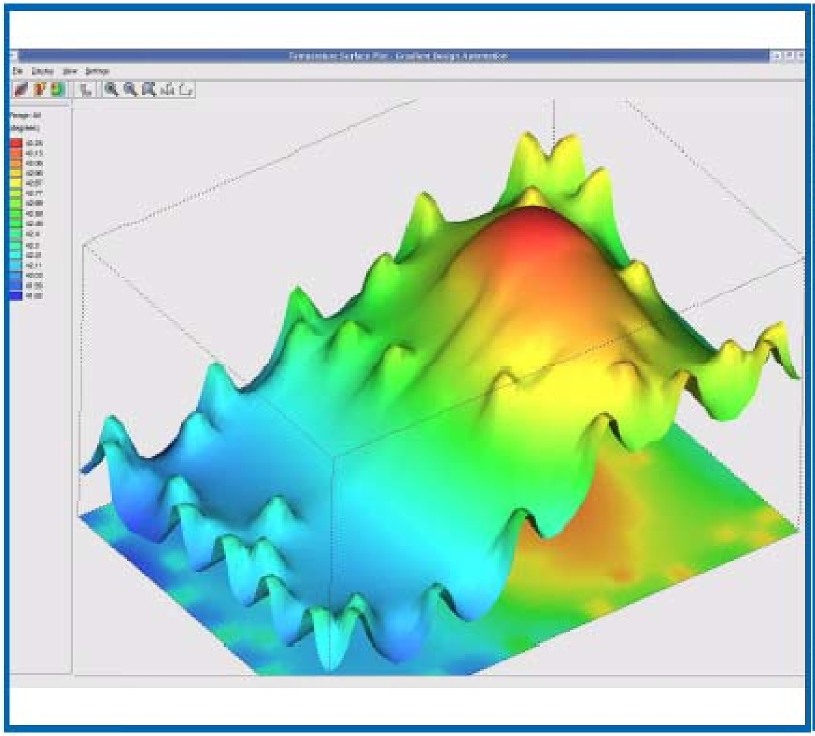
- Heatwave: Co-development with Gradient
  - **Circuit simulator** & **thermal simulator** based on:
    - Schematic
    - Layout
    - Package and bonding
    - PCB (position, size, material)
    - Module + air-flow



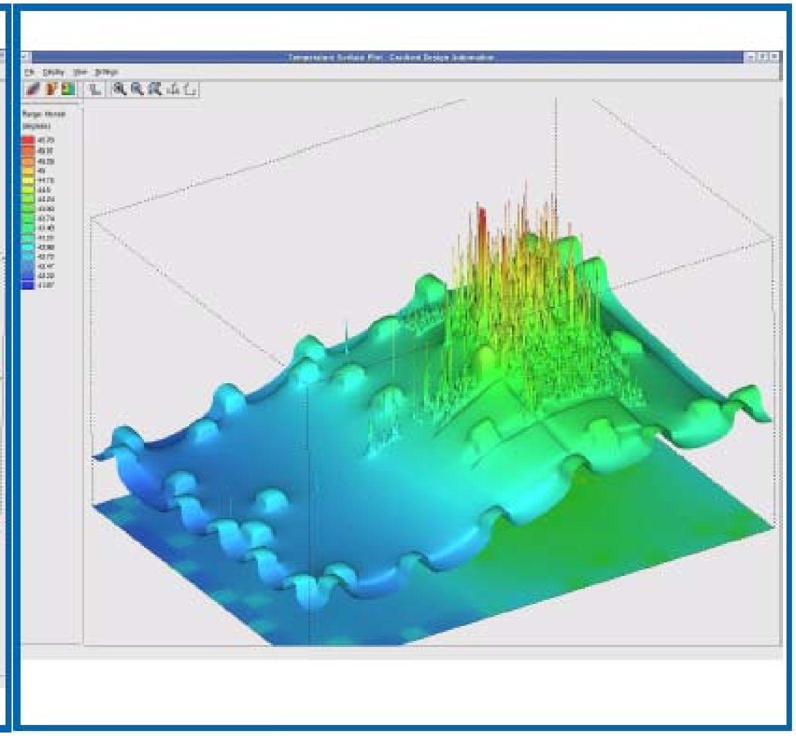
Electro Thermal Simulation

GRADIENT

Support fine-grain analysis for accuracy - of hotspot magnitude and location



Coarse-grain

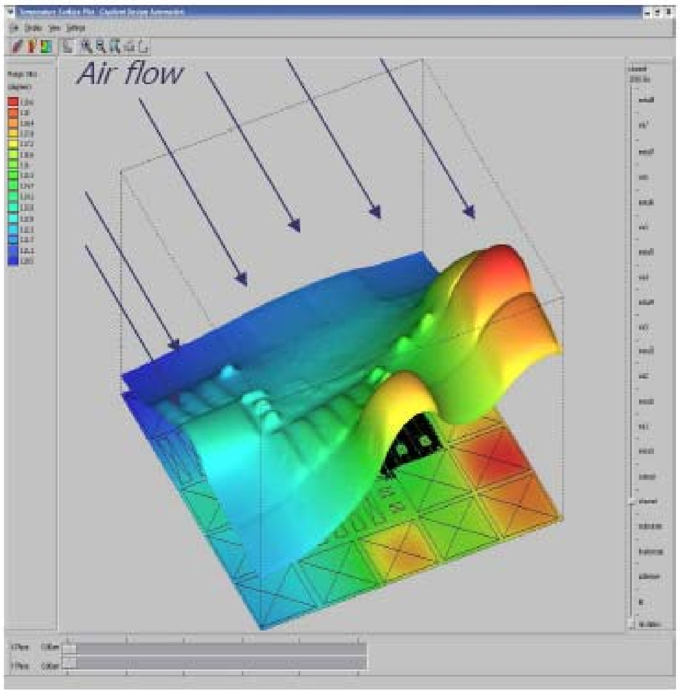


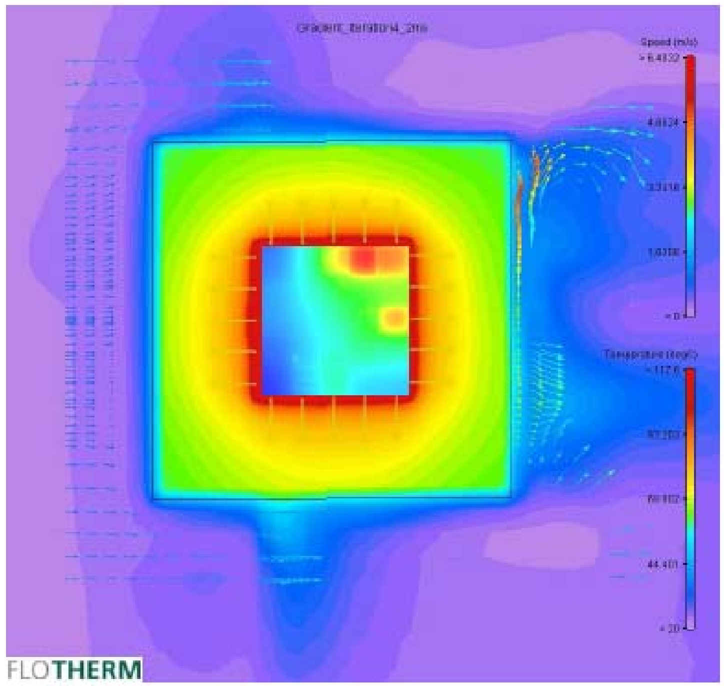
Fine-grain

Electro Thermal Simulation

GRADIENT

Takes package and ambient into account





x 8.50 in

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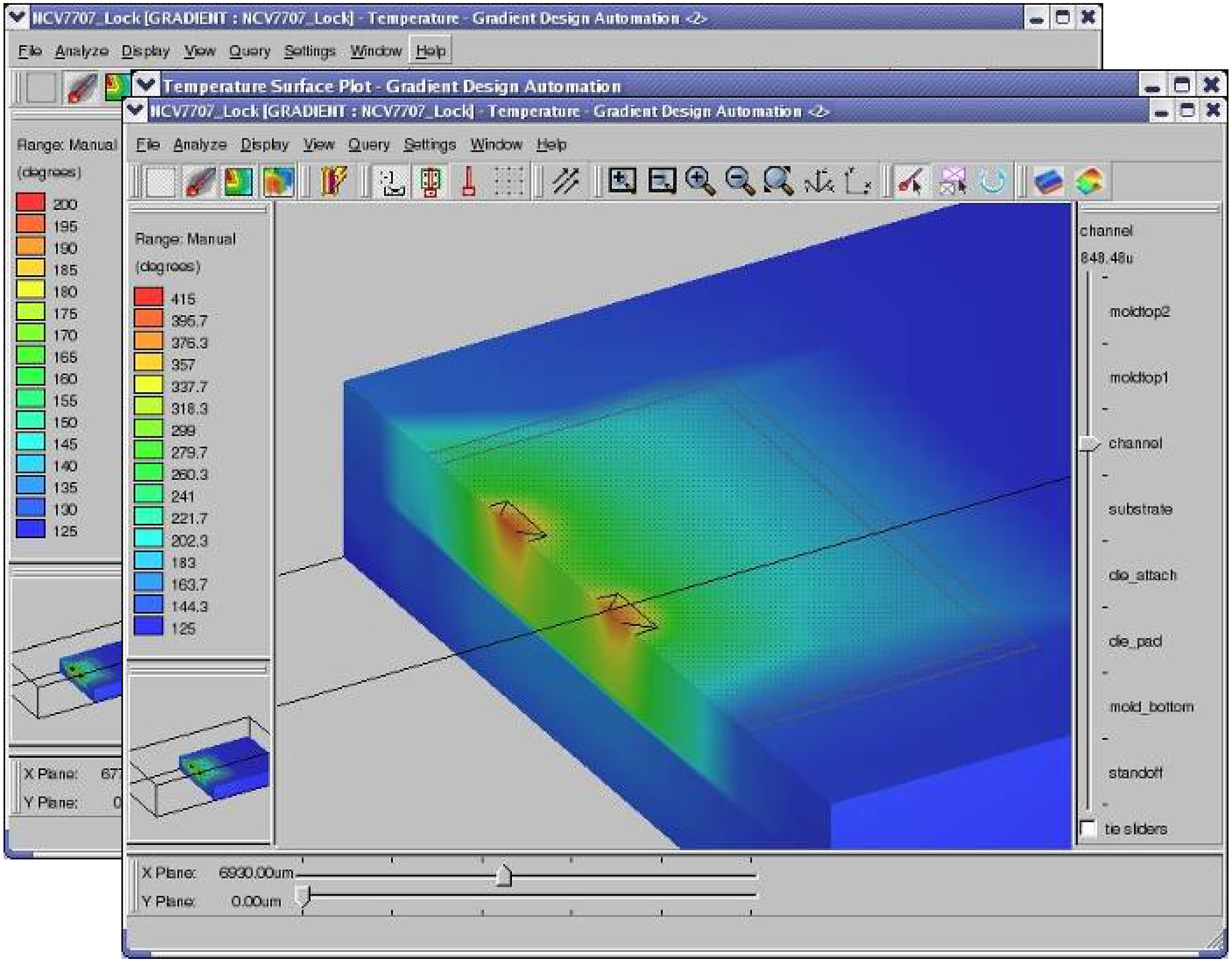
Simulation of Door-lock

- Normal operation (after 500 ms)
- Three dimensional plot
- Short circuit condition (after 500 ms)



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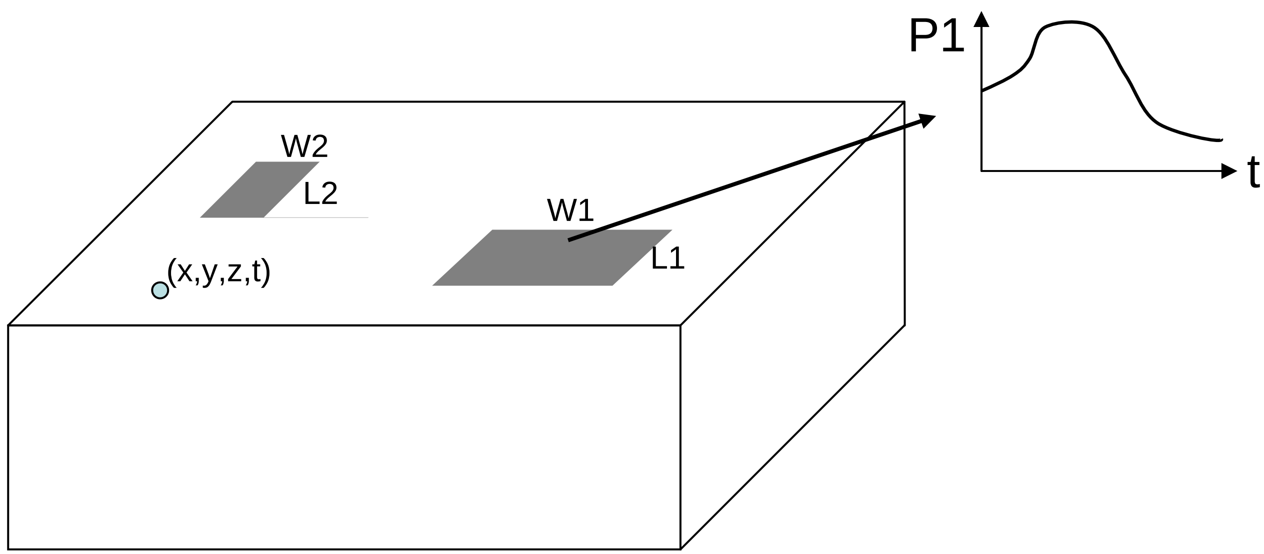
Thermal Simulators

- Hot spot floor-plan simulator (ON Semiconductor-tool):
  - Based on analytical equations = solution of the heat diffusion equation for a homogeneous rectangular power source. (Developed together with IMEC within the frame of the **COMPOSE**-project)
  - At **silicon**-level: based on die-edges, the surface and no limit in depth.



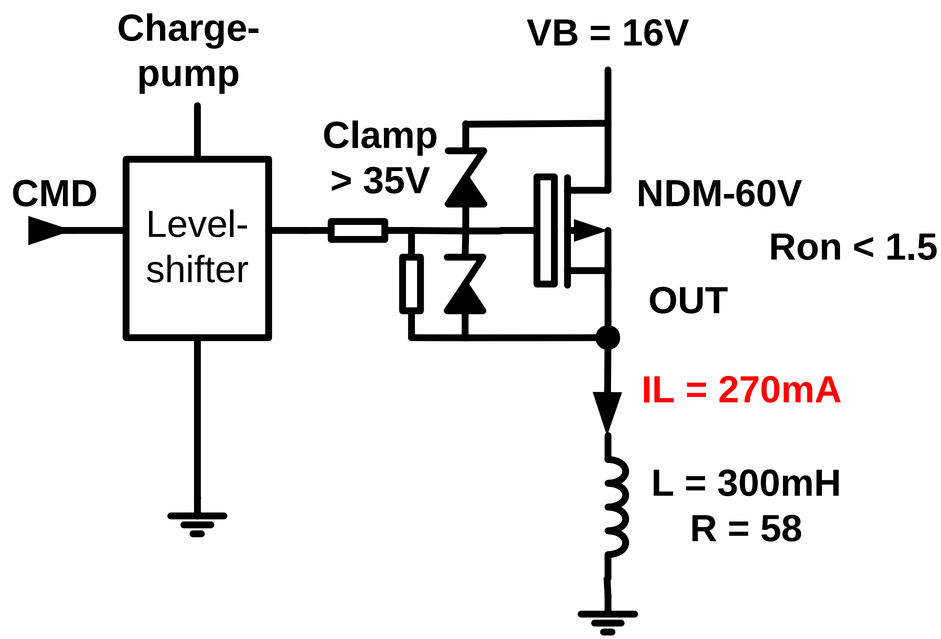
AMIS-39100: Octal HS-driver

HS-driver:

- 8 x HS-driver: Ron < 1.5 Ω
- DC-power ~ 1 W
- Peak-power during clamp
  50 V x 0.27 mA = 13.5 W

Questions:

- What is the peak-temperature?
- What is case of 8 HS-drivers?
- What is the best place for the TSD?
- Impact on quality and reliability?

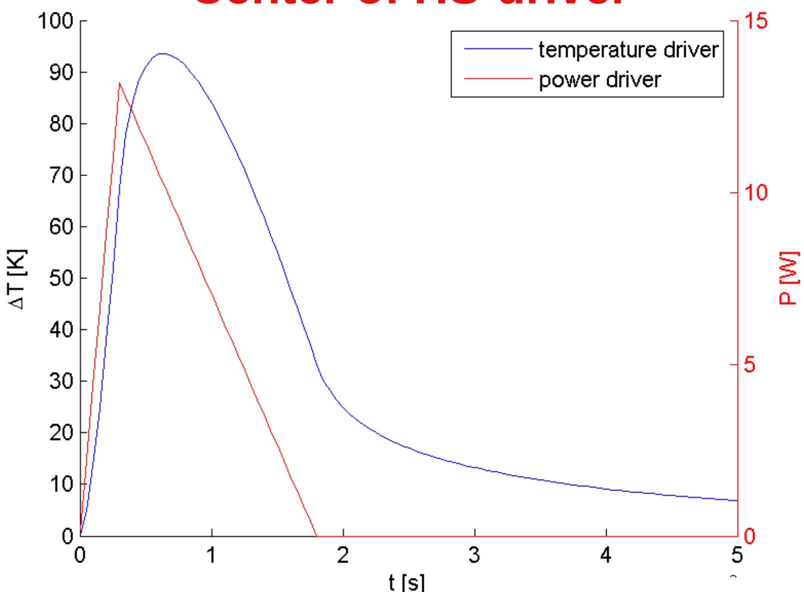


AMIS-39100: Octal HS-driver

Simulation results (1):

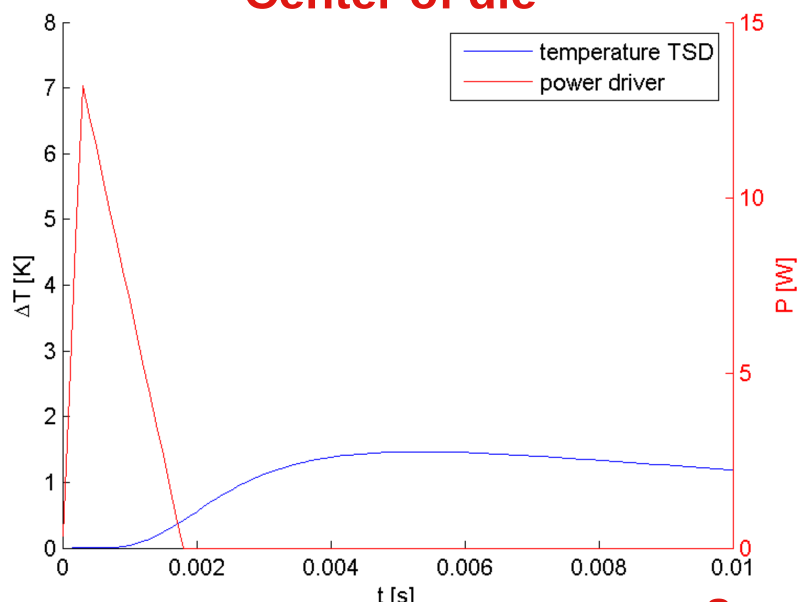
- Switching of one driver with 300 mH at 270 mA.
- Peak-power: 13.5 W at 0.2 ms
- Peak-temp: Tamb + 95 C at 0.6 ms

Center of HS-driver



ms

Center of die



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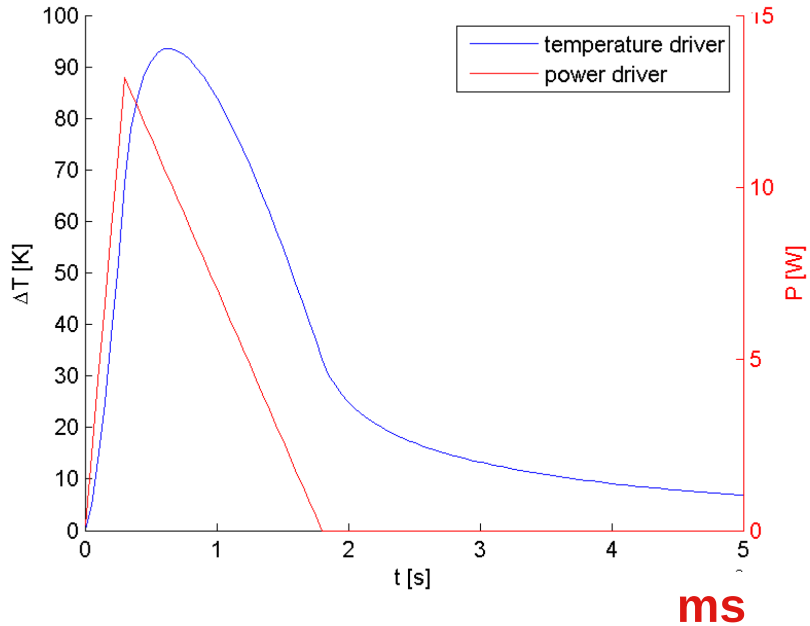
AMIS-39100: Octal HS-driver

Simulation results (2): 8 HS-drivers

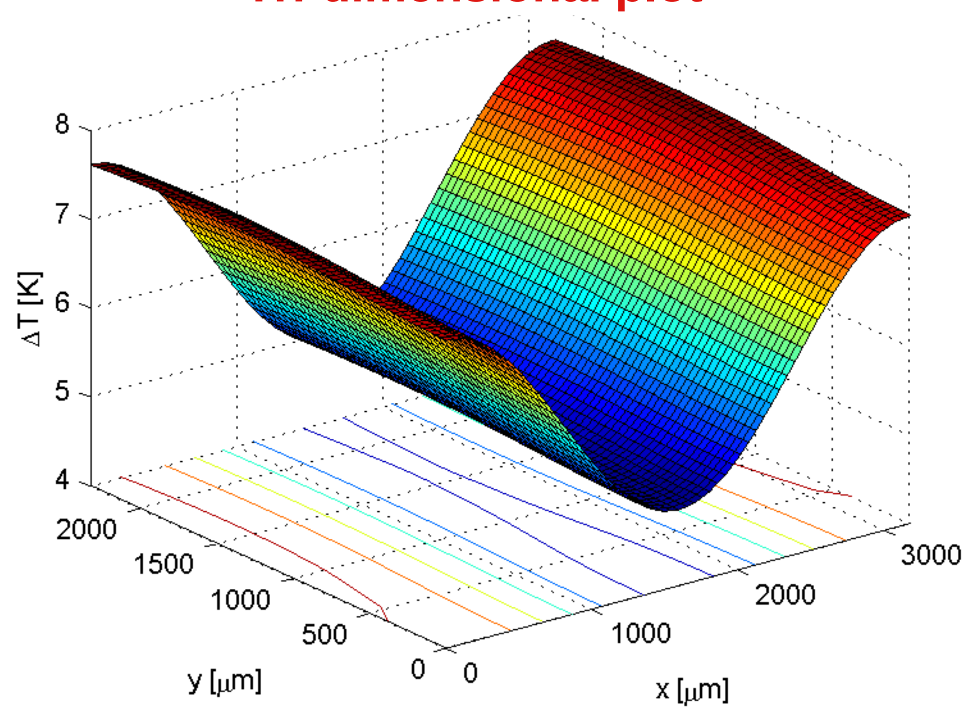
- Switching of one driver with 300 mH at 270 mA
- Peak-power: 107 W at 0.2 ms, Peak-temp: Tamb + 95 C at 0.6 ms

10 ms

Center of HS-driver



Tri-dimensional plot



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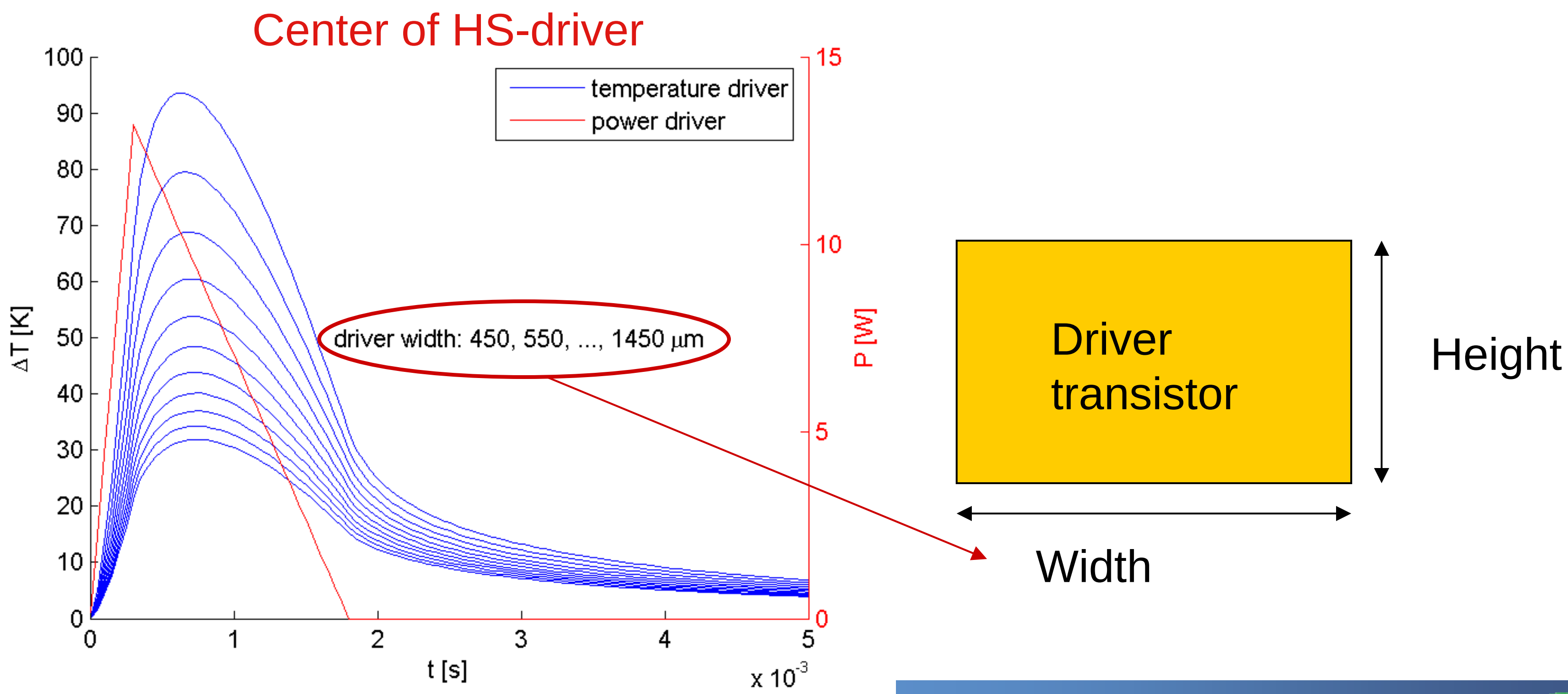
AMIS-39100: Octal HS-driver

Simulation results (3):

- Switching of one driver with 300 mH at 270 mA
- Constant area but different aspect ratio:



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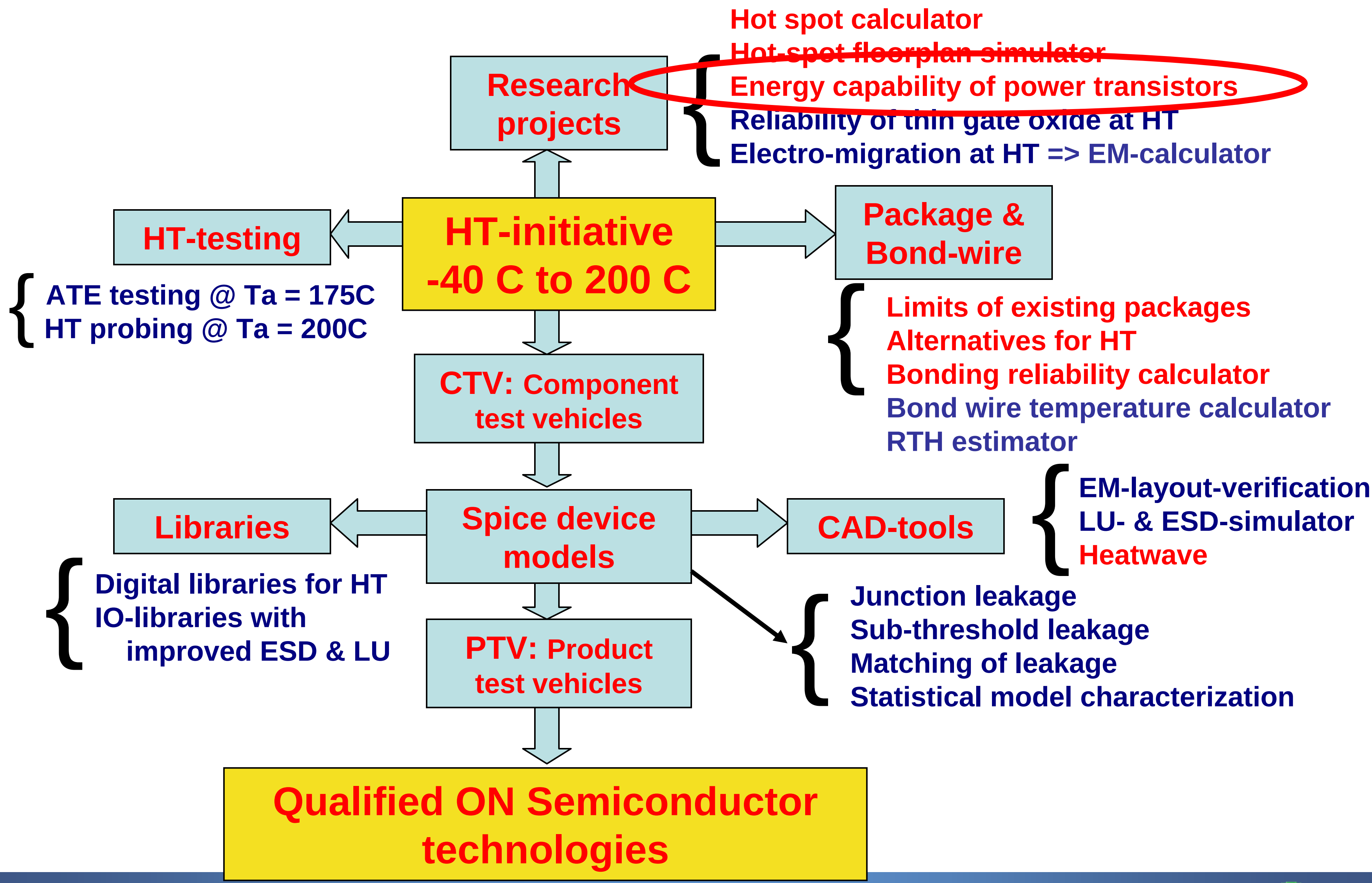
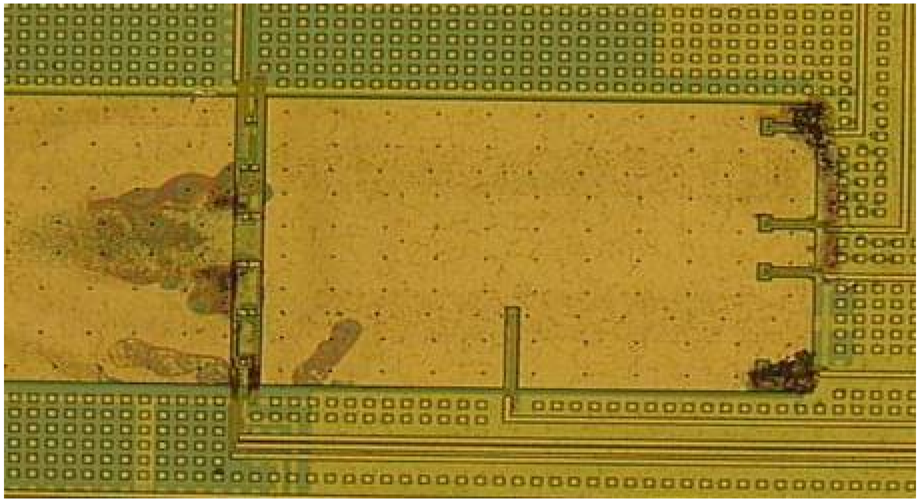


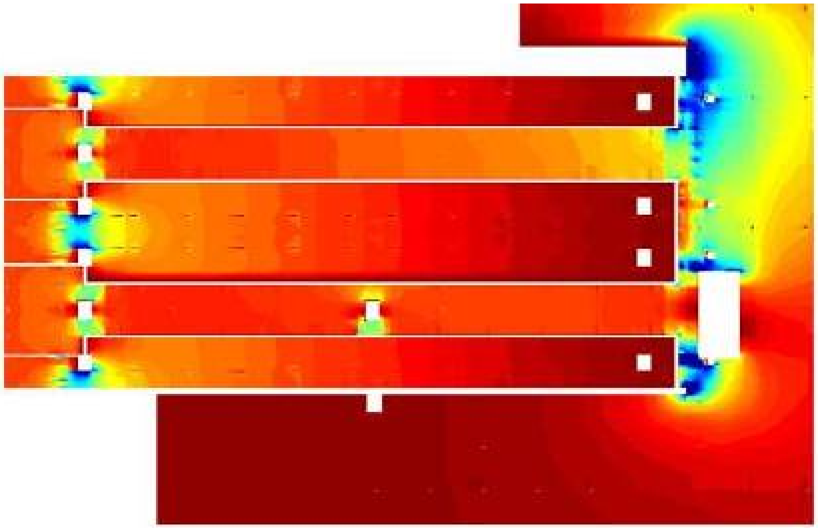
Definition of a Hotspot

- A hotspot is a limited area of silicon that is allowed to go temporarily above the maximum uniform Tjunction allowed for the technology
- Current target :
  Peak temperature of 300°C, for a cumulated total on-time of the power-pulse limited to 24 h
  (on top of the standard temp. profile of the technology)
- In those conditions, the standard aging mechanisms (BTI, HCI, EM) have not enough time to significantly degrade the transistor performance
- But it is more likely that a gradient-driven mechanism will dominate the device degradation
  (cfr previously metal migration effects)

Conclusion on Backend Reliability (Pulsed)

- Even 24 h at 300°C in the backend stack, combined with the standard temperature profile for the IC is a challenge
- Bondwires come loose after 48h at 300°C plus 500x cycles
- Metal migration is occuring in the same conditions and first cracks are being formed
- Need to watch uniformity of current density !





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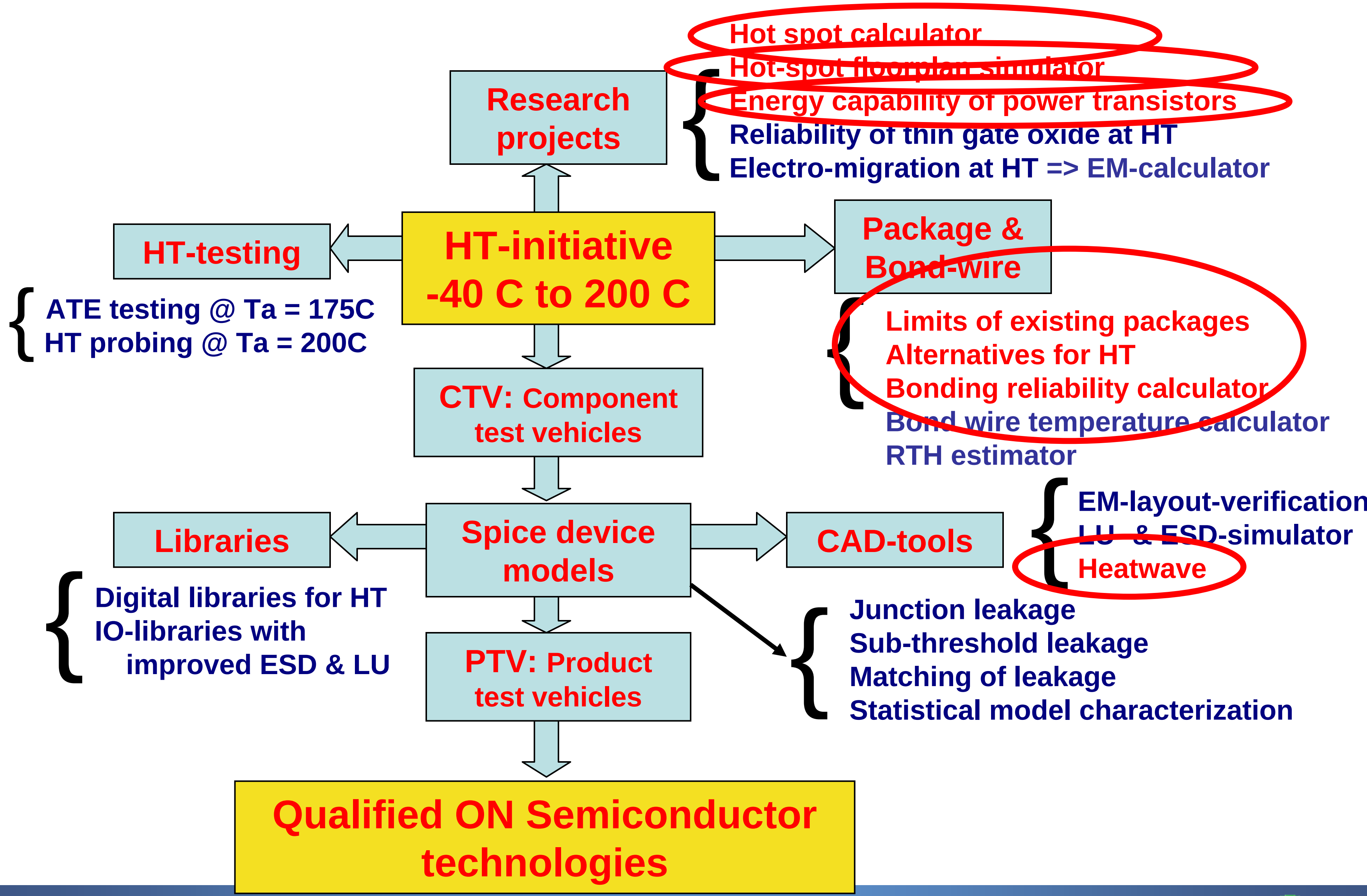
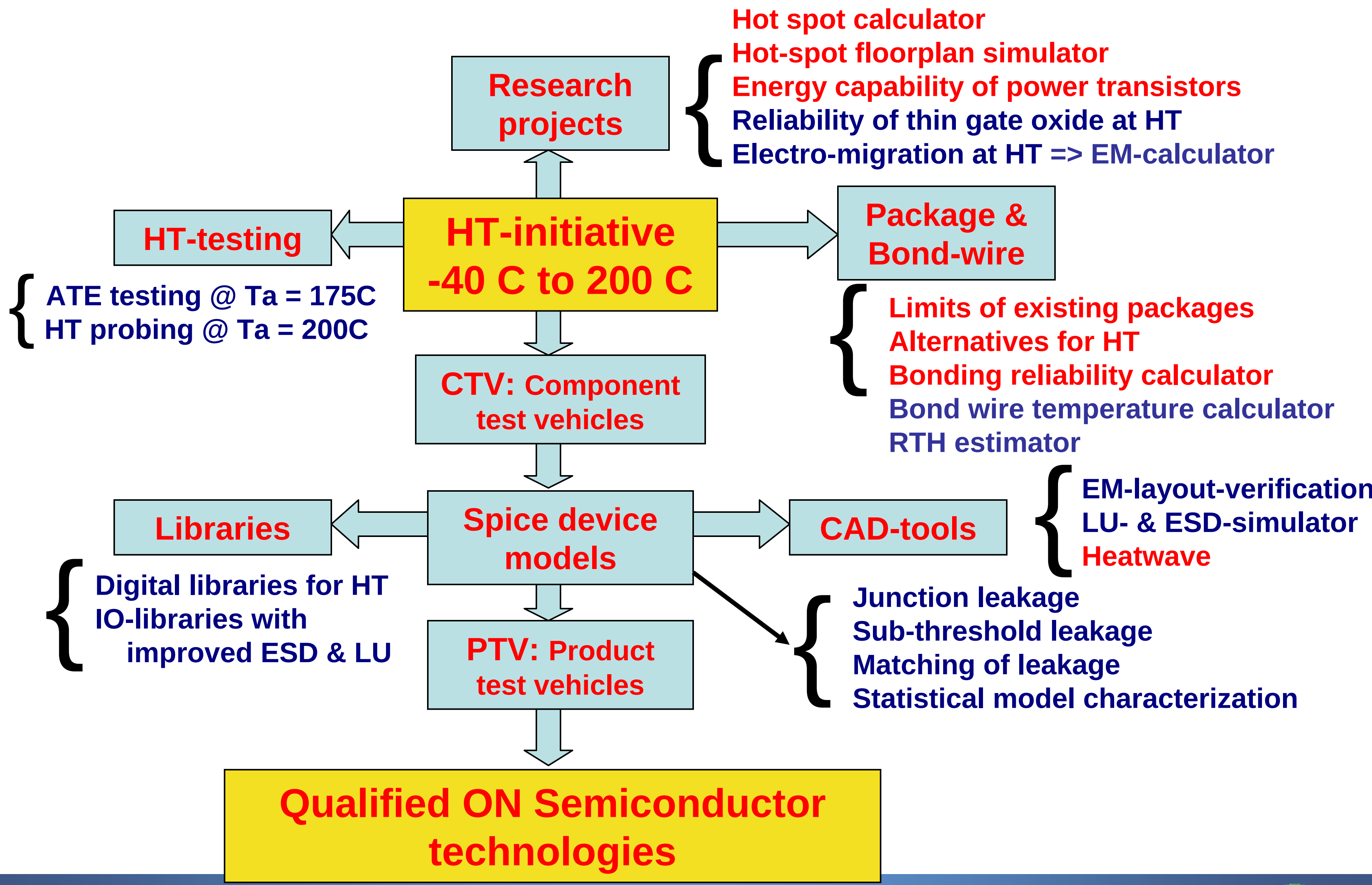


Limits for HT-applications

- Package & bonding reliability: Starts < 150 C
  - Is the **most severe constraint** that limits life time !!
  - **Solutions up to 200 C** exist, at a higher cost.
- Thermal models: > 150 C
  - Require improved thermal models for:
    - Transistors
    - Leakage, Electro-Migration
    - Latch-Up & ESD
  - **Hot-spot floorplan simulator**
  - **Heatwave**
- Device reliability + Electro Migration
  - **DC operation** till **Tj=200 C**: **OK**
  - **Pulsed operation** till **Tj=300 C**, limited duration: **OK**
  - **Thermal run away** above **Tj=550 C**

HT-initiative at ON Semiconductor



For More Information

- View the extensive portfolio of power management products from ON Semiconductor at www.onsemi.com
- View reference designs, design notes, and other material supporting automotive applications at www.onsemi.com/automotive