IEEE SW Test Workshop
Semiconductor Wafer Test Workshop

Aspects of High Power Probing

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June 12 to 15, 2011 … San Diego, CA

Overview

- Power semiconductors: …some applications and examples
- High current probing – happenings… and a definition
- Thermal modelling of probe and bond pad
- FE simulation results
- High current probing using multiple "bussed" probes
- Current symmetrization
- Case study: STM automotive power device

High Power Devices - Applications

renewable energy, electric trains, power grids

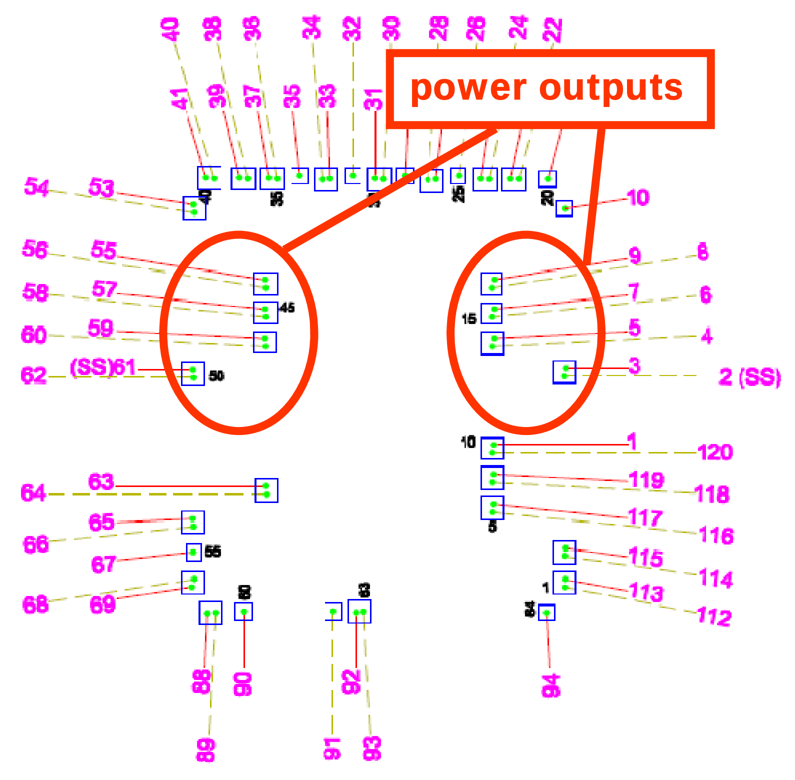
IGBT power module

automotive electronics

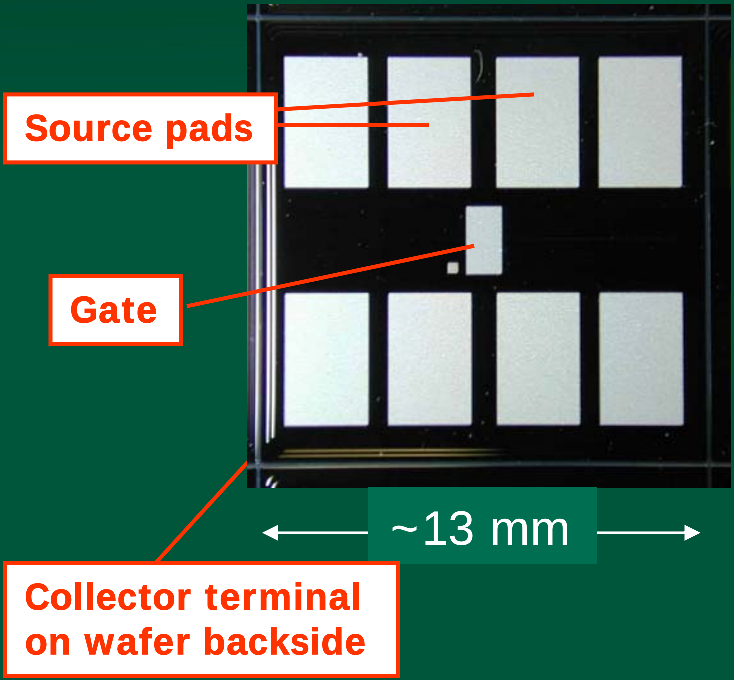
electromobility…

computer
power
supply

Power Semiconductors - Examples



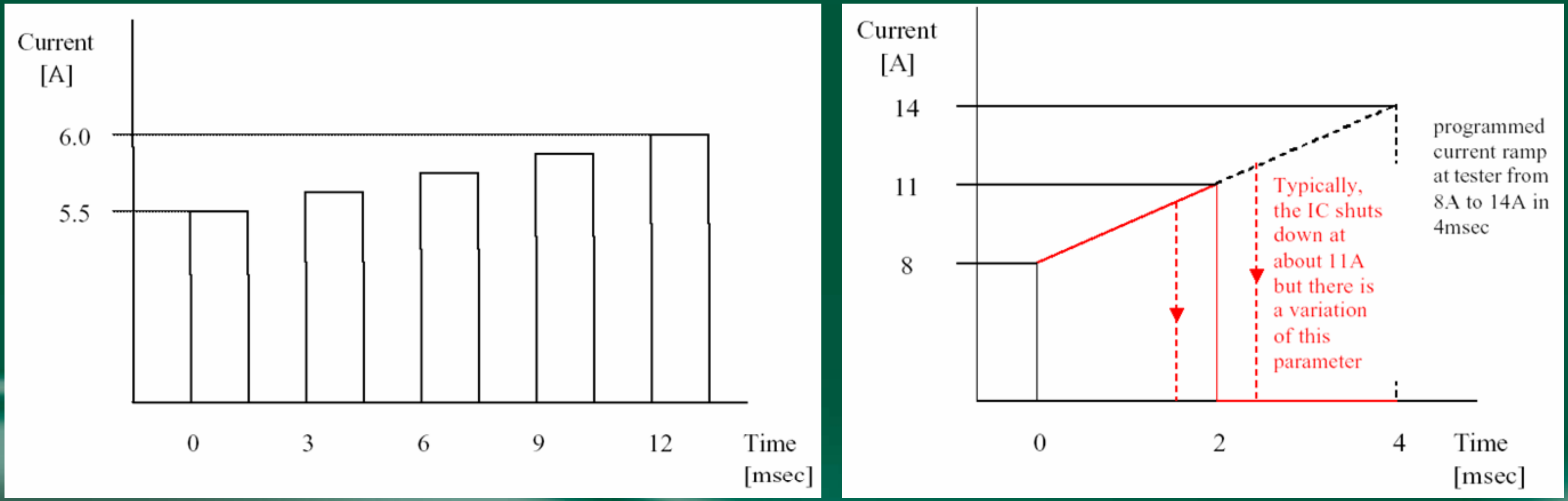
Probes layout for automotive power ASIC: 12 A, 2 outputs (high side/low side bridge)



2 kV / 100 A IGBT power switch

… some Power Tests

- Power Transistors: electrical "on" resistance for e.g. MOSFETs, IGBTs, SiC devices
- Diode forward current voltage drop: e.g. high current rectifier diodes, SiC high efficiency switching diodes
- Verification of overcurrent protection circuity in "intelligent" power switches, automotive ASICs



programmed current ramp at tester from 8A to 14A in 4msec

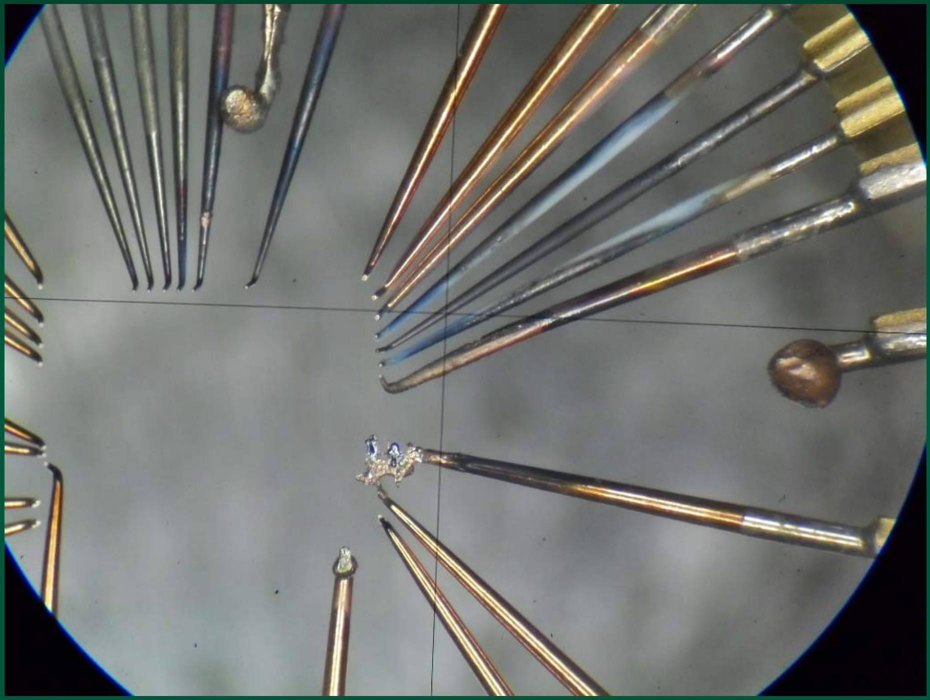
Typically, the IC shuts down at about 11A but there is a variation of this parameter

Timing diagrams for typical power tests

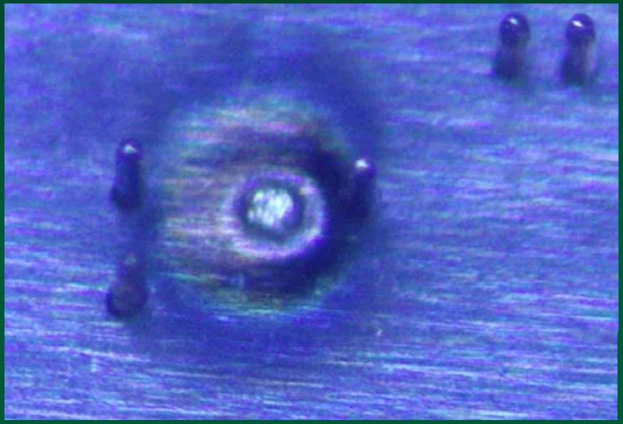
High Current Probing …a Definition

- High Current Probing can be characterized by:
  - Pulsed currents on power outputs: typically 1-5 A per probe / a few milliseconds, one or several pulses
  - Current amplitudes higher than maximum DC current rating of probe

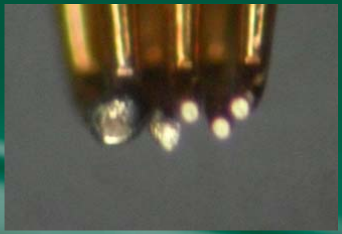
High current probing – happenings…



"catastrophic burn"



"evaporated" vertical probe tip



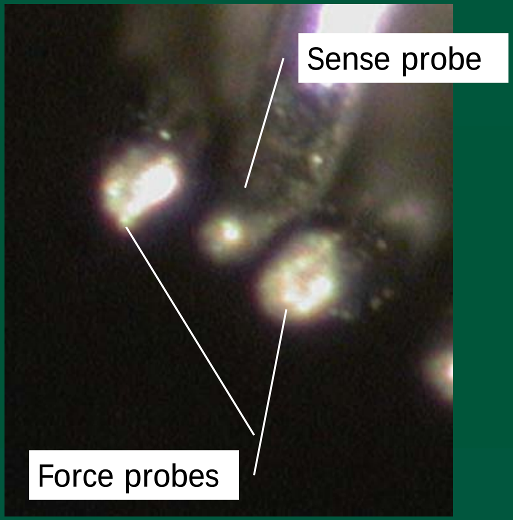
molten tips

probe tip contamination

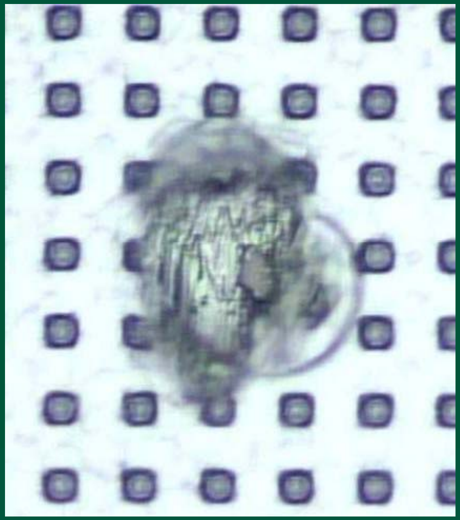
…and occurences

- High wear of probes, tip contamination
- Overheated, burnt probes, loss of contact force
- Molten contact areas on bond pad

new probe tips

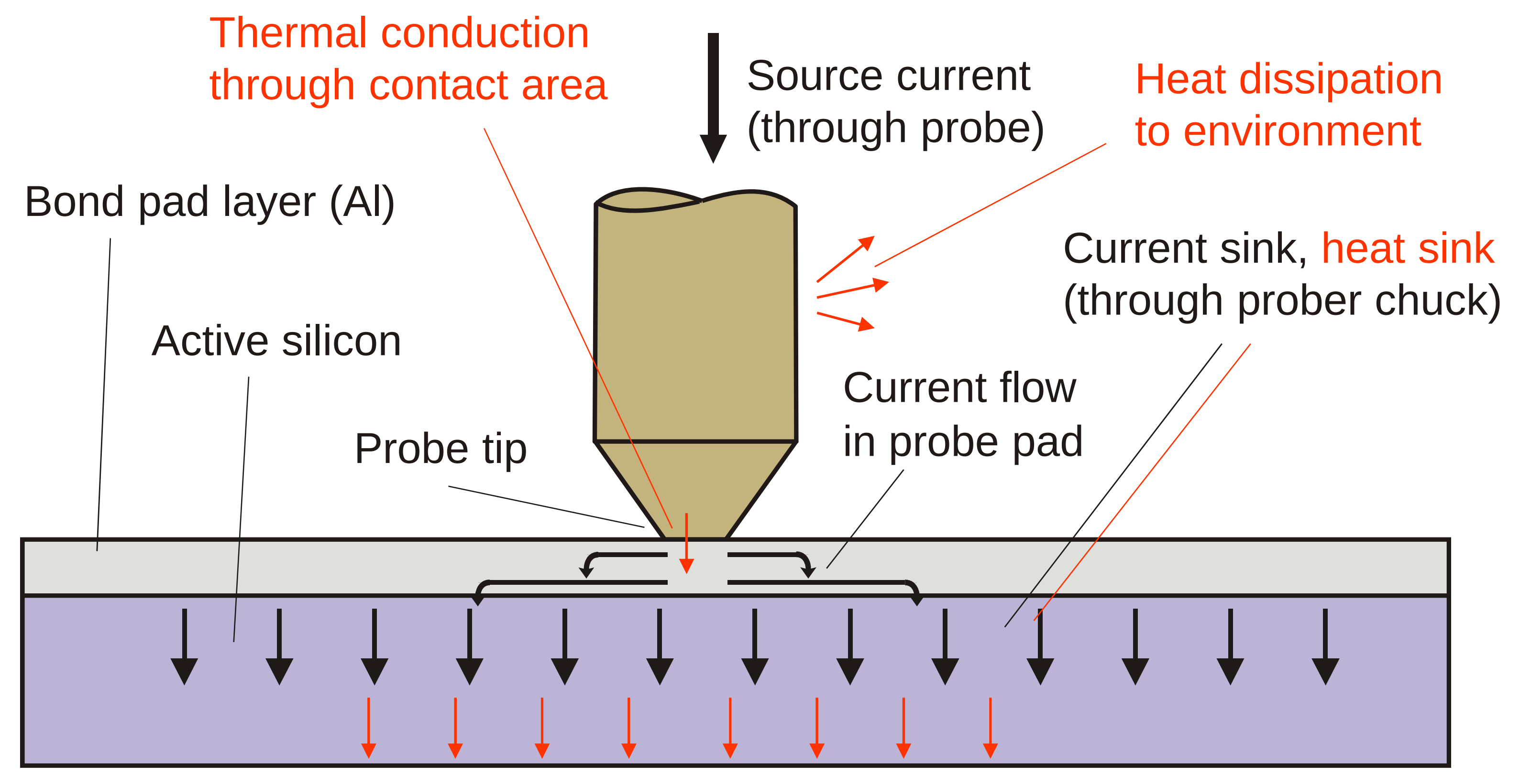


pad material contamination on high current probes



molten probe mark

Electro-Thermal Modelling



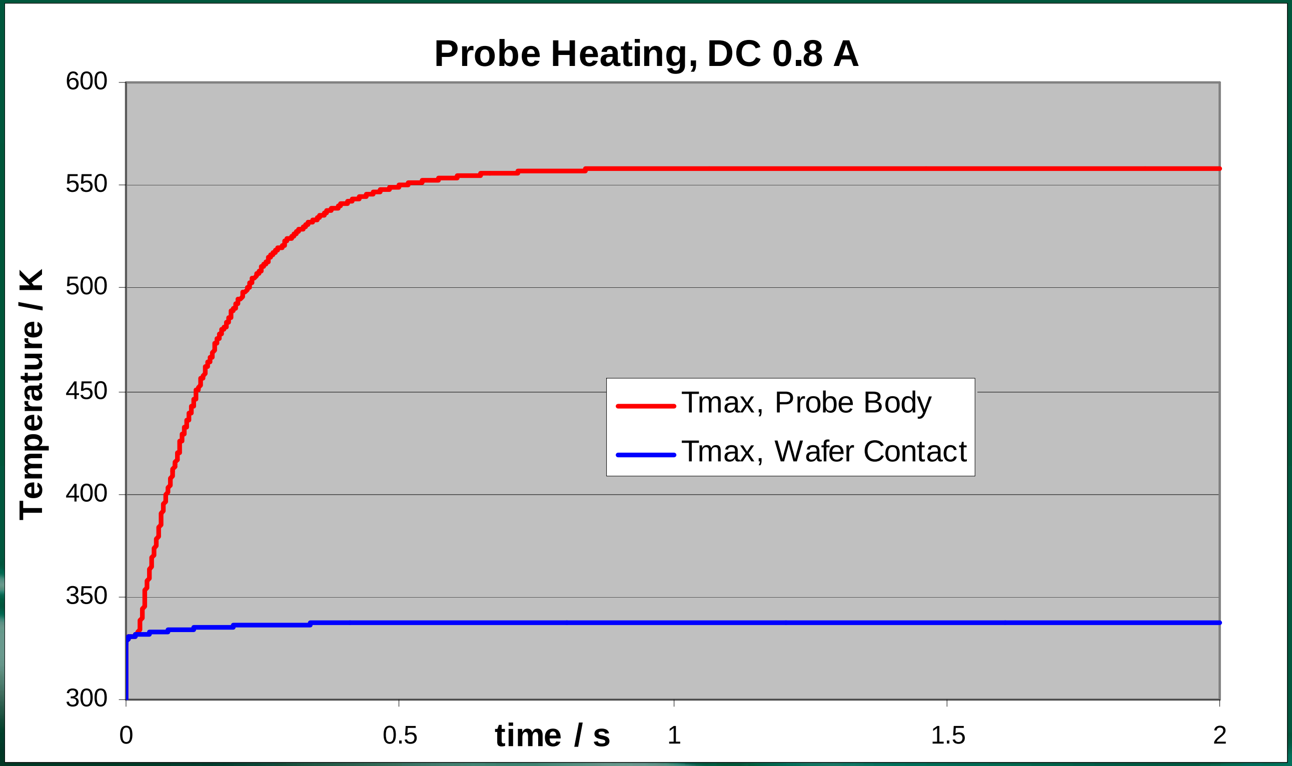
model of electrical and thermal current flow in probe and bond pad

Electro-Thermal Modelling (2)

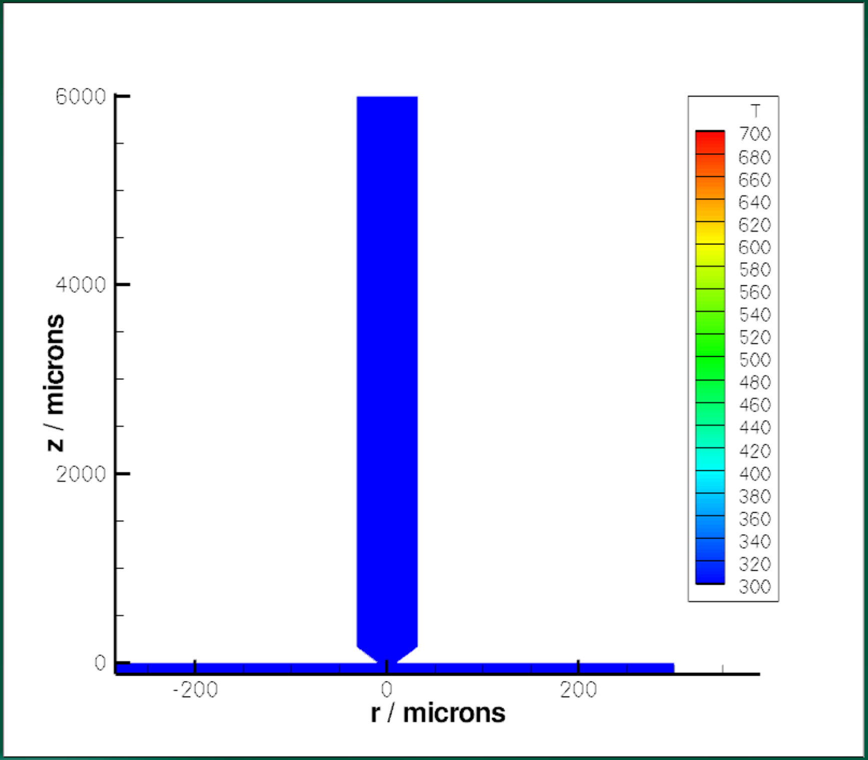
- "Finite Volumina" method for numerical solution of an "Instationary Thermal Equation"
- Parameters:
  - time-dependend electrical heating (pulsed currents)
  - material parameters (material resistivity, thermal conductivity,
  - contact resistance
  - heat dissipation to environment
- Dedidated software code created that runs on a conventional PC or workstation

Simulation Results – DC current

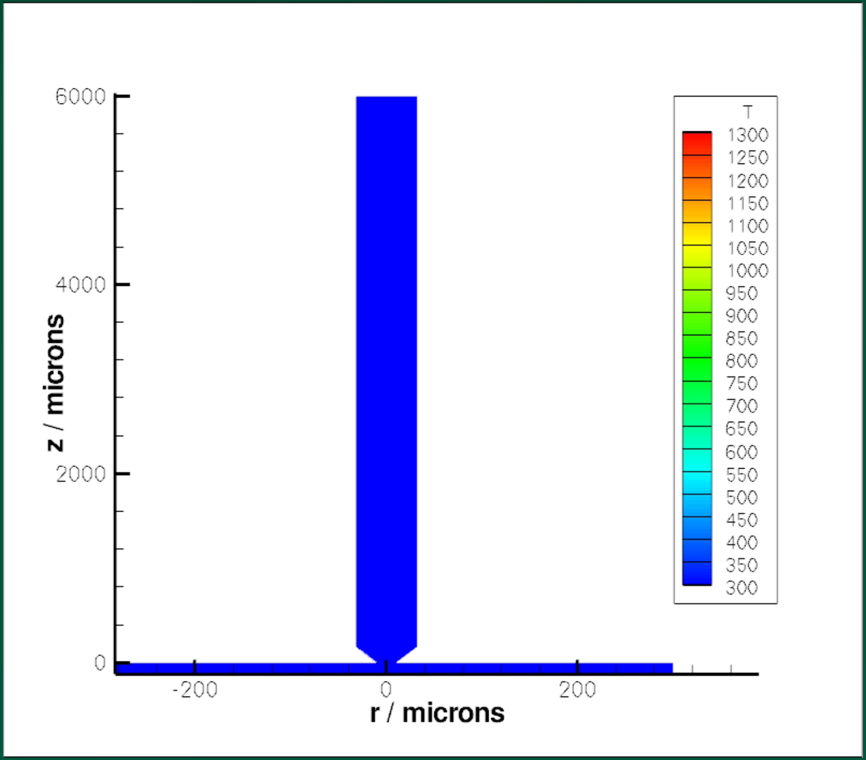
- limiting factor: **probe body heating**
- DC current limit: max. continuous heat dissipation
- probe tip remains relatively cool



DC - "Animated"



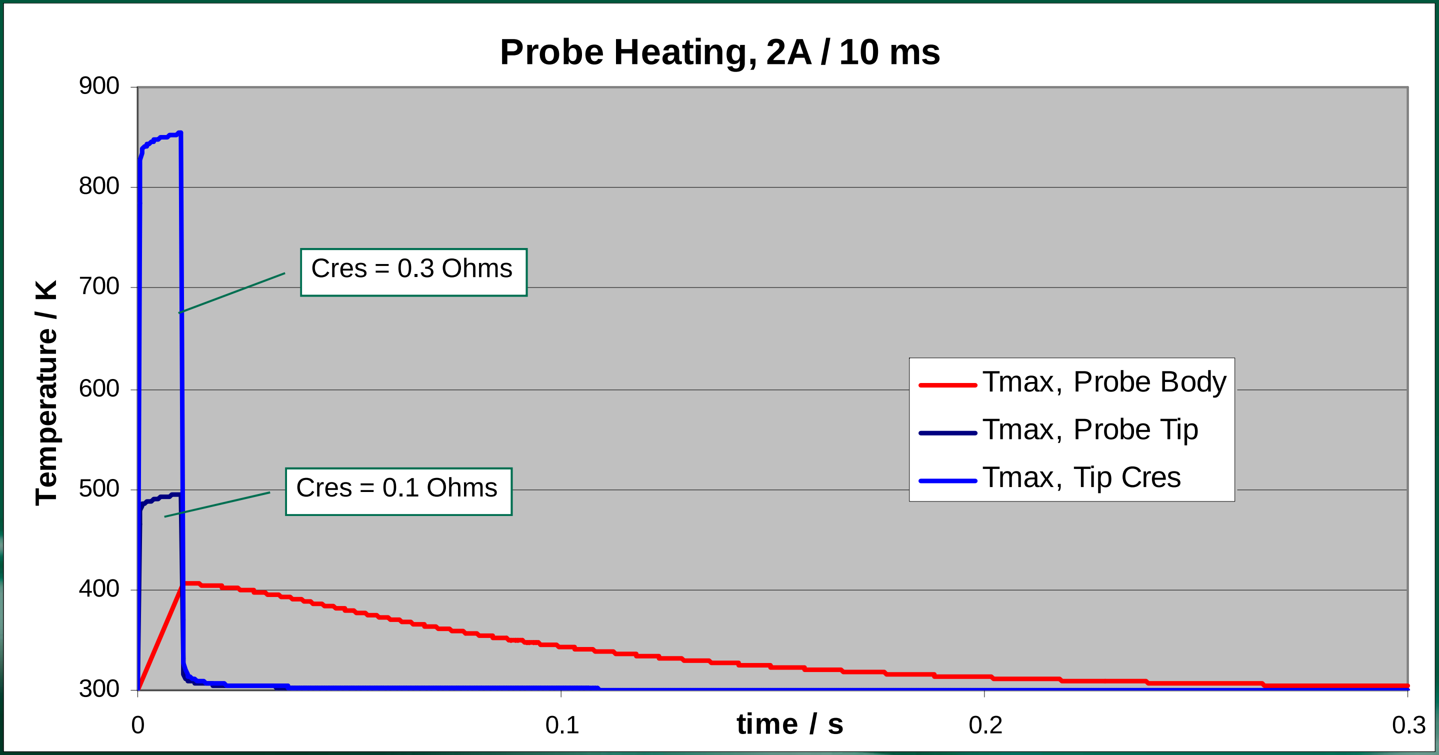
DC heating of probe / wafer contact



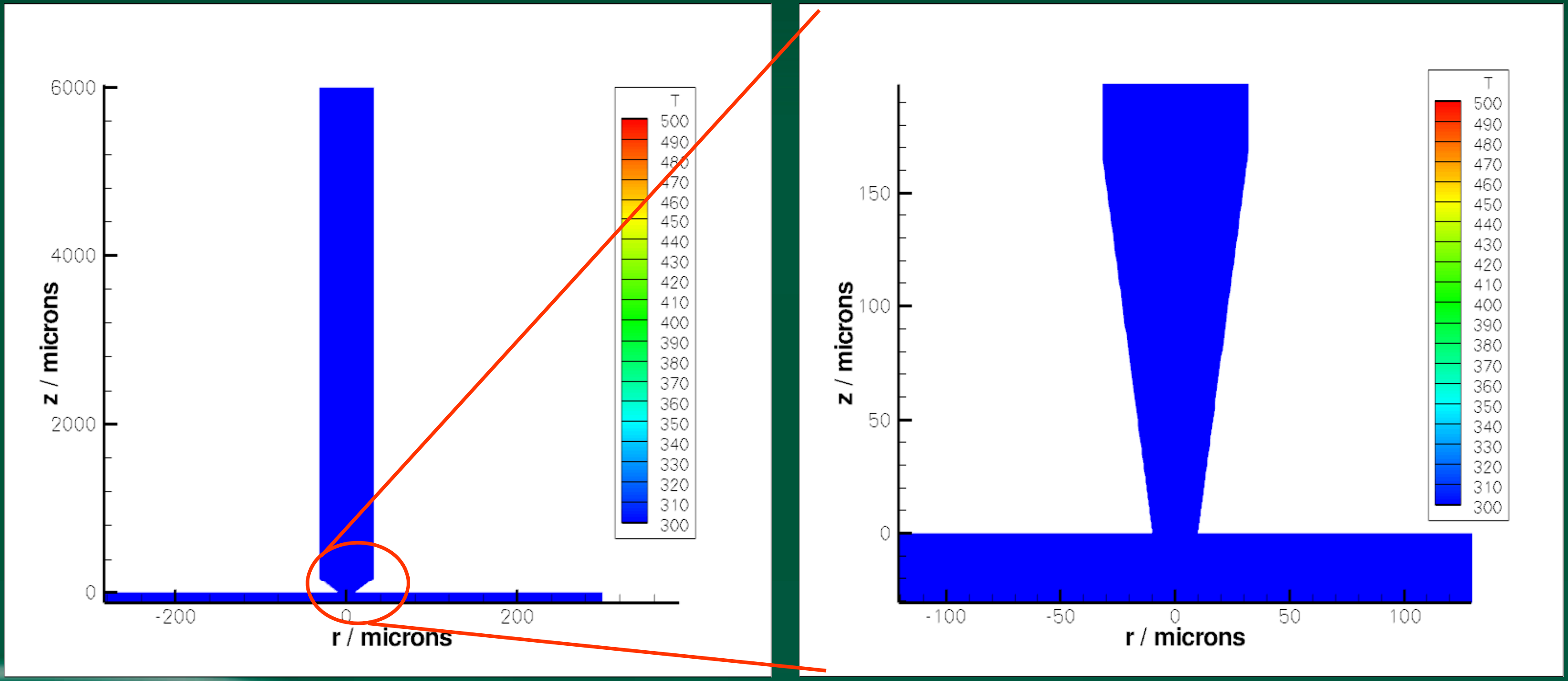
DC "catastrophic overload"

More Results – Single Pulse

- peak current higher than max. DC current
- limiting factor **probe tip heating:** very fast and strongly dependent on contact resistance Cres
- "long" cooling time – determined by the time needed to dissipate heat from probe body to environment



Single Current Pulse – "Animated"

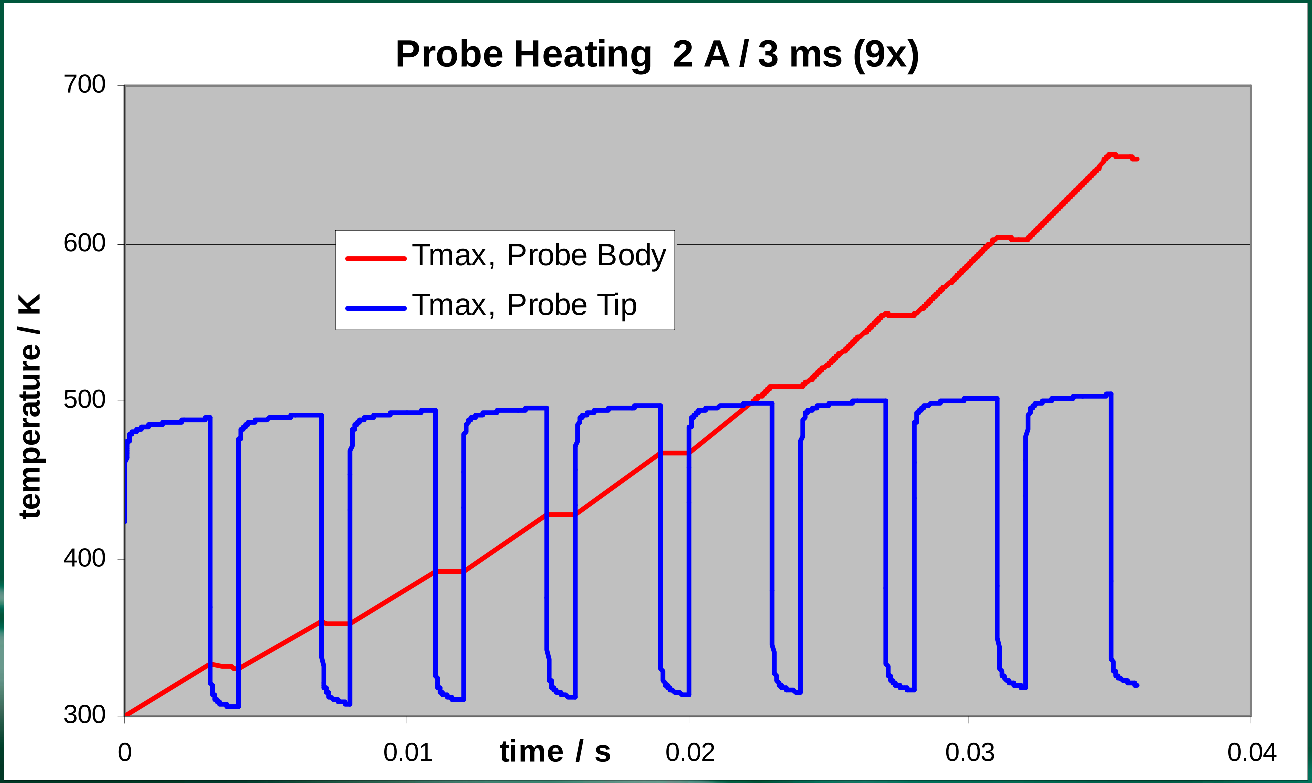


pulsed heating of probe / wafer contact

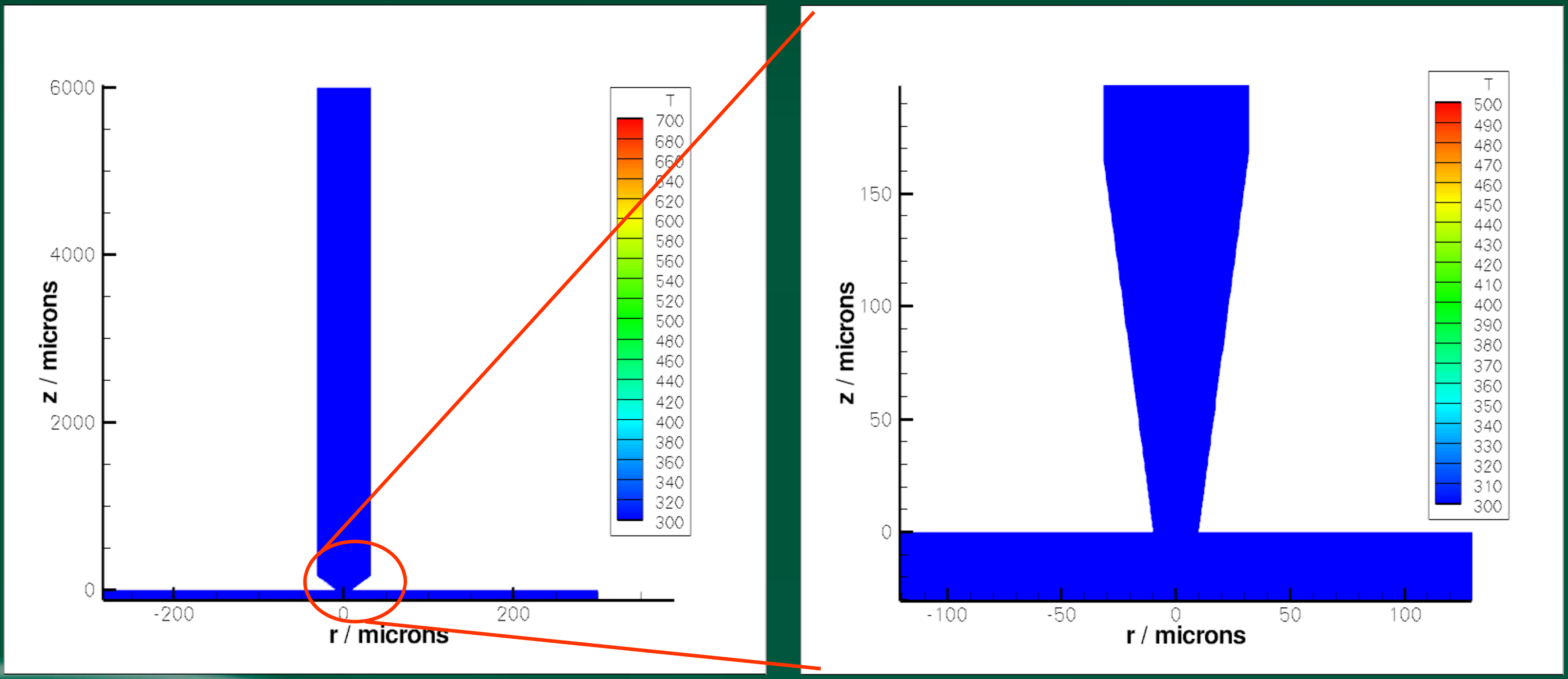
probe tip "zoomed out"

Current Pulses Sequence

- limiting factors: **peak current** AND **number of pulses** in sequence
- very fast probe tip heating and cooling - "quasi-DC"
- "slow" decay for probe body temperature



Pulses Sequence – Animated



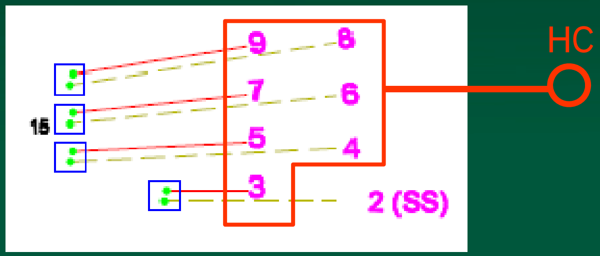
Conclusions from Simulations

- 2 regimes for high current probing:
- Probe tip heating
  - very fast
  - sensitive to short current spikes
  - sensitive to high contact resistance
  - pulsed current overload: high probe tip erosion and tip contamination, but probe body remains intact
- Probe body heating
  - "slow" heating, slow cooling, insensitive to current spikes
  - DC overload: probe "burn", thermal discoloration, loss of contact force

-> Safe Operating Area (SOAR) for probes can be defined implementing DC and pulsed current regime

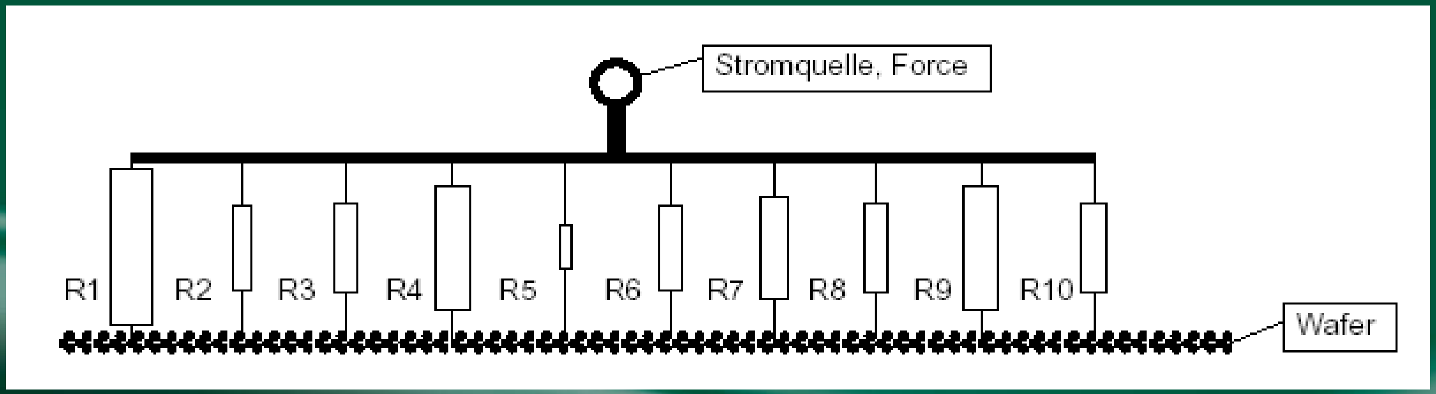
Protecting Probes – Case Study ST

- ST automotive power ASIC, 12 A low / high side switch

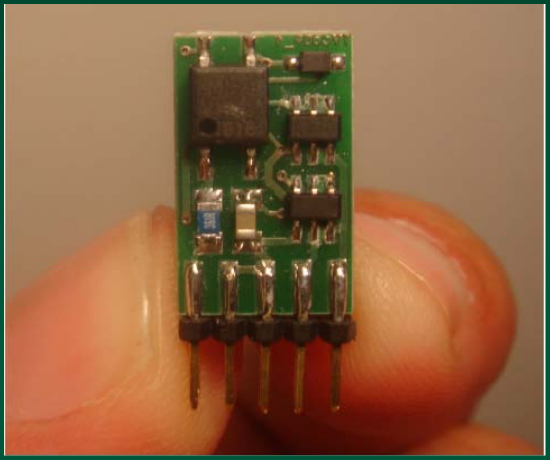


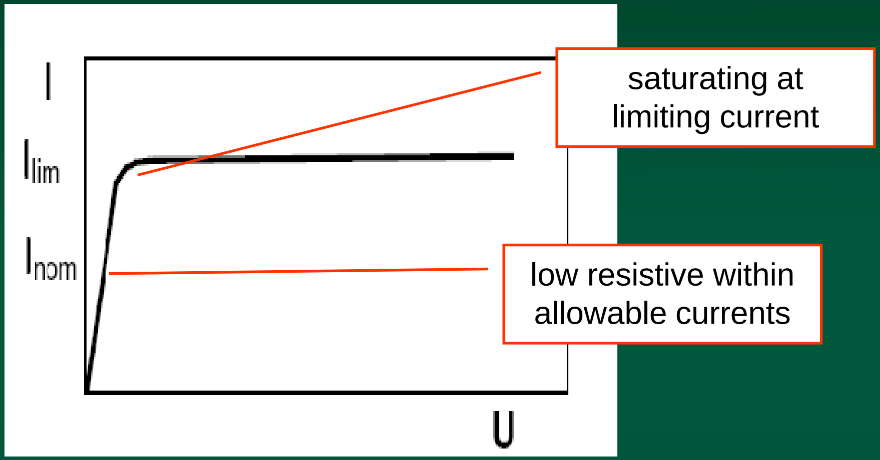
  - 7 probes bussed to power supply, random probe burns on power pads, high probe wear
  - nominal current per probe does not exceed specs, so why?

-> unsymmetric current distribution amongst probes due to Cres variations



"MicroClamp" Current Limiters





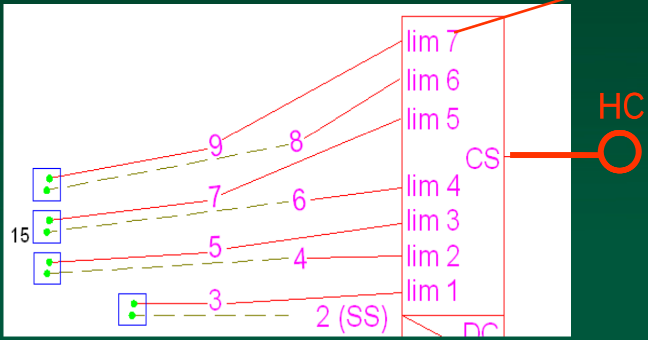
saturating at limiting current

low resistive within allowable currents

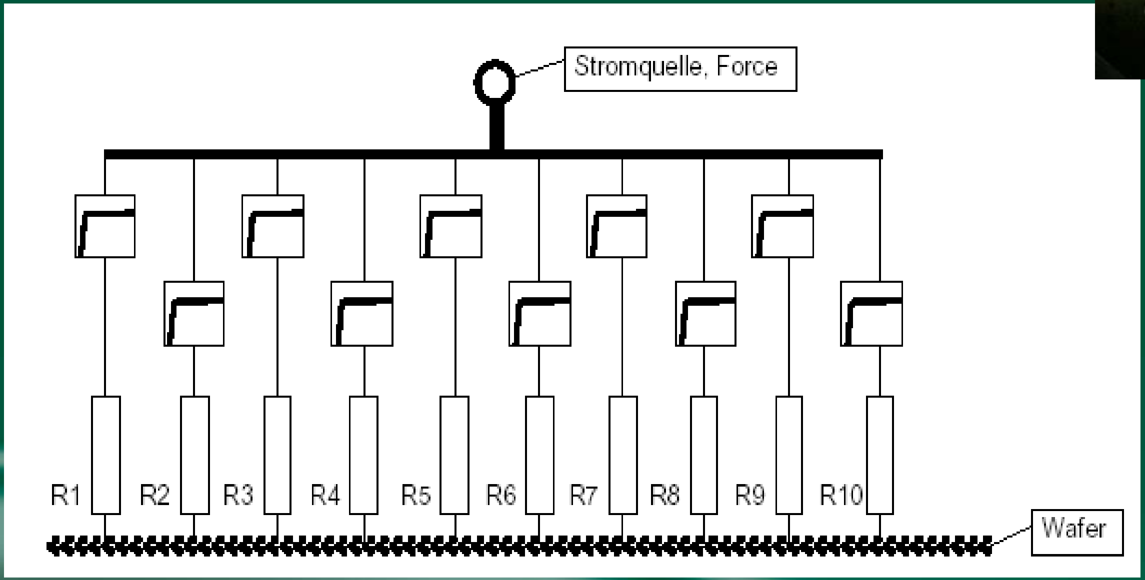
"MicroClamp" module, electrical characteristics

- Clamping unwanted current spikes effectively protects bond pads and probes from thermal damage
- Galvanically insulated – easy to integrate into test circuitry
- Low resistive within allowable current range -> "transparent " to tester circuitry

Active Current Symmetrization



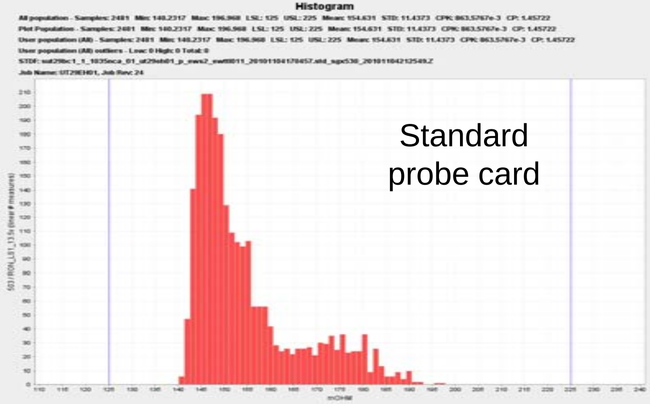
MicroClamp module inserted into the high current path

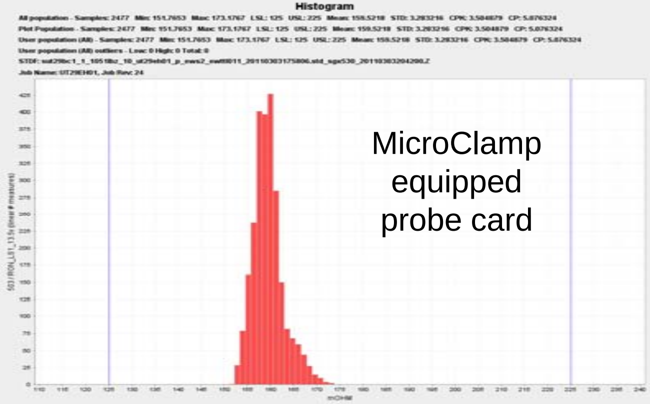


Active current symmetrization and individual probes protection

Unexpected Findings

- besides effectively protecting the probes from burns (what was the purpose of the project)….*therefore, we can conclude that the V3 uClamp probe card showed the ability to prevent pinburns without affecting the test results of the device. (STM statement)*
- …interesting effects on <u>Test Statistics</u> were found:





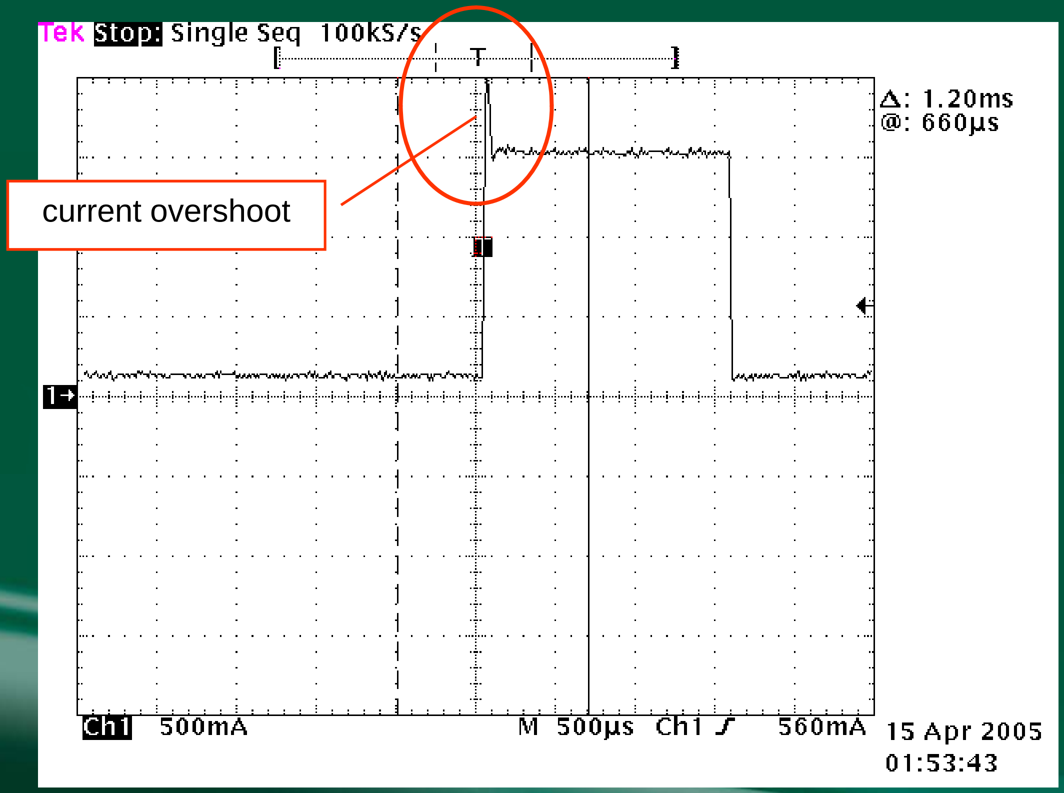
standard deviation reduced by 75 %

R_{DSON} distribution on wafer, approx.150 mOhms, hot test

- Explanation: uniform current distribution through probes to test pads due to "active current symmetrization" leads to less variation in R_{DSON} measurements.

… more bad things for probes

- Overshoot current spikes (e.g. due to contact fritting)
- "Slow" overcurrent protection in tester power sources
- Dirty probe tips: contact fritting, high tip temperatures



current overshoot

Summary

- High current probing reveals some challenges that are not present in "static" DC probing .
- Using **numerical simulation** tools, **"Safe Operating** Areas" for both DC currents and pulse current regimes can be defined for specific probe geometries and materials.
- In case of high currents: **Keep your probe tips clean!** ☺
- "Half the pulse time – twice the current" rule of thumb has only limited validiy...
- Clamping unwanted current spikes by use of **MicroClamp** circuitry effectively protects bond pads and probes from thermal damage.

Acknowledgements

Named and unnamed contributing to that work:

- Sherwin UY, Kin-Loong NG, Kyaw Win MAUNG and others, ST Microelectronics Singapore
- Jeanie Tan, TIPS Asia Pte. Ltd.
- our staff in TIPS Messtechnik GmbH
- Infineon Technologies AG

Thank You !