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High pulsed current wafer probing in high temperature conditions: comprehensive framework for vertical and cantilever probe design

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Wafer Probing Technologies

Outline

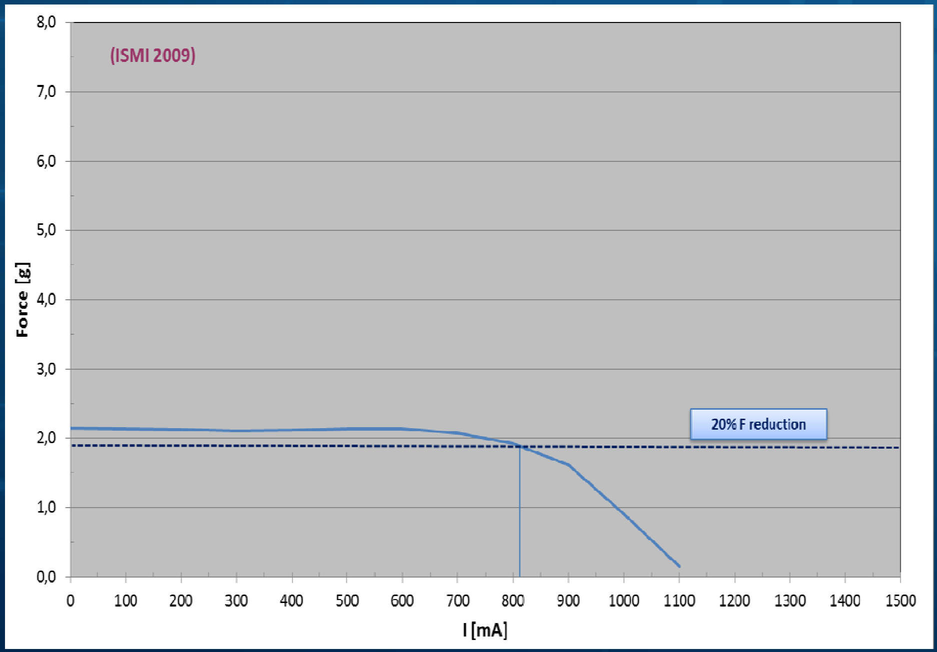
- **Background**
- **Description of tested probes and testing vehicles**
- **Resistance transients**
  - Measurement setup and results
- **Model description**
  - Assumptions and numerical scheme
  - Features
- **Comparison of experimental data with model data**
- **Numerical code application**
- **Conclusions and further work**

Background

- **High temperature, high current testing represents a challenging working condition in wafer probing technology.**
- **Mainly Automotive Customers are requesting us to predict maximum current carrying capability of a single probe in real production conditions**
- **In this work we summarize our basic experiments and modeling of the thermo-electrical behavior of both vertical type and cantilever type microprobes considering:**
  - Different geometrical configurations and different probe materials (Tungsten, Cu alloys, precious metal alloys)
  - Real probing conditions

Background

- **ISMI CCC measurement method for vertical probes**
  - **CCC is the “Current Carrying Capability”, defined as the maximum direct current that can be carried by a probe without damage (“burning”) for an indefinite time.**
  - **ISMI method is widely adopted to evaluate the CCC for vertical probes.**



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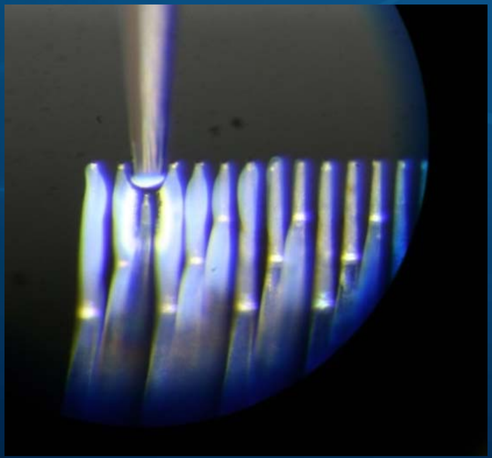
In the graph a typical measurement of CCC for a vertical probe is reported.

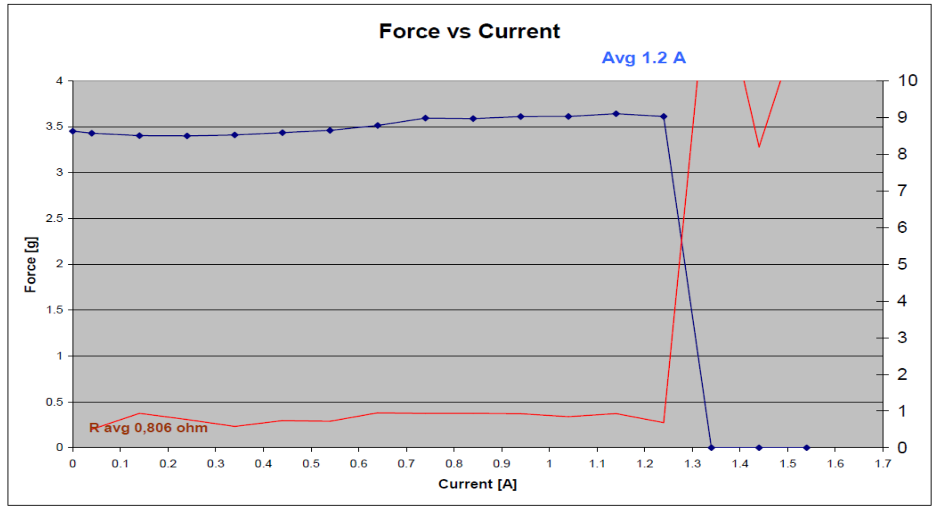
Here CCC is 810 mA.

Force reduction is due to probe heating that leads to a drop in probe stiffness.

Background

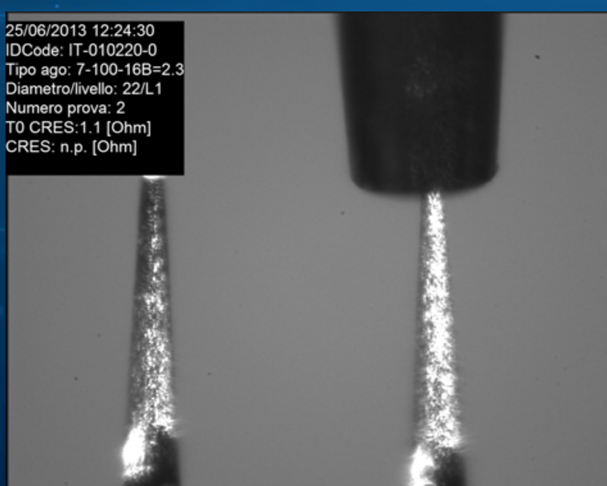
- **Max CCC for cantilever probes**
  - ISMI method seems to be not suitable for WR cantilever probes
    - WRe has a melting temperature of 3380°C and heating of the needle body during the test isn't enough to induce a force degradation.
    - The tip portion of the probe acts like a fuse, protecting the body from excessive heating and consequent stiffness degradation. The contact force is approximately constant until the tip is melt, in contrast with the physical principle behind ISMI method (20% force degradation).





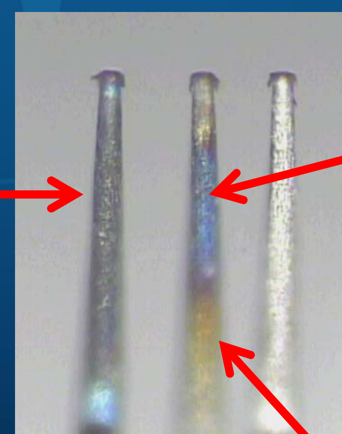
Background

- **A way to define Cantilever probes CCC could be as follows: “maximum continuous current value for which the probe does not undergo any visible tip burning after 5 minutes of solicitation”.**
  - Tip “burning” is identified by tip discoloration due to any oxidation optically visible.
  - Oxidation mechanism is very slow when the tip undergoes a small temperature increment (200-500°C) but becomes much faster when the tip reaches a temperature higher than 1200 °C (10 ÷ 200 ms)



↑ example of test setup

WO_2 Black
Fast Oxidation around 1100°C



$W_{20}O_{50}$ Blu-Violet
Fast oxidation around 1600°C

WO_3 Yellow
Slow oxidation around 1400°C

Test vehicles

Probe features

- **Two different kind of needles have been considered:**
  - Vertical TPEG™ MEMS T4 needle
  - Cantilever NoScrub™ needle
- **Needle main features:**

TPEG™ MEMS T4

Features	Value
Length	L_{ref}
Alloy	High current alloy
Thermal diffusivity	α_{ref}

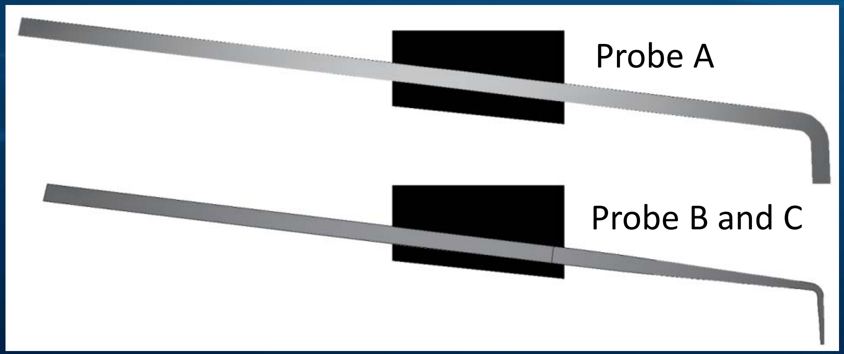
Cantilever NoScrub™

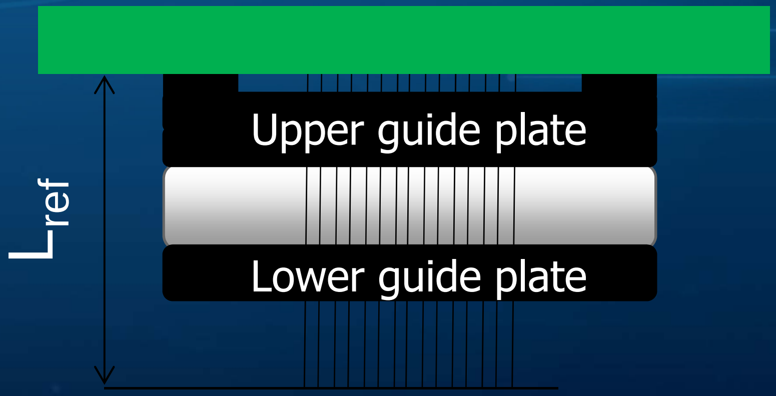
Features	Value
Length	$0.28L_{ref}$
Alloy	Standard alloy
Thermal diffusivity	$0.54\alpha_{ref}$

Test vehicles

Probe features

	Description	Test Current (mA)
Probe A	WRN4 mils (No Taper) Contact diameter = 100 µm	650 mA 850 mA
Probe B	WRN4 mils Contact diameter = 16 µm	650 mA
Probe C	WRN4 mils Contact diameter = 23 µm	850 mA
TPEG™ T4	Contact diameter = 30 µm	1.2 A

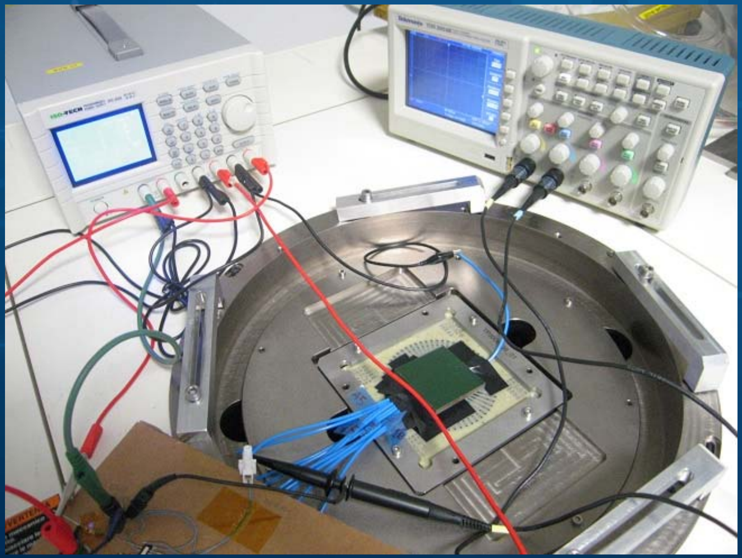




Experimental Setup

Time constants measurements

- **The picture below shows the experimental setup:**
  - The probe card (Cantilever or Vertical PH + Space Transformer) is loaded on (TEL P8XL) prober.
  - Power supply and oscilloscope are connected to the probes under test.
  - Probes are contacting a wafer (Au or Al blank wafers)



Cantilever Setup

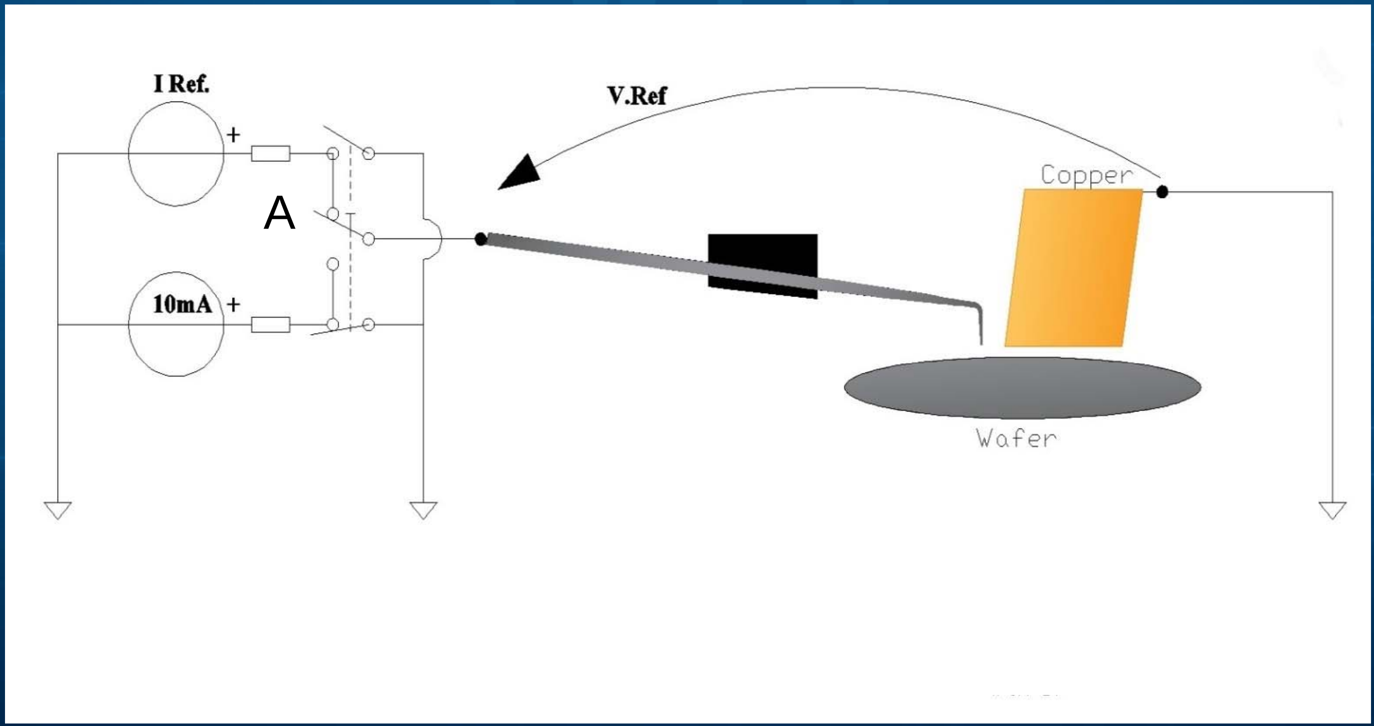
Vertical Setup

Experimental Setup

Time constant measurements

- **Cantilever measurement setup simplified schematic**

$$R_{probe} = \frac{V_{Ref}(T,t)}{I_{Ref}} = R_{probe}(T,t)$$



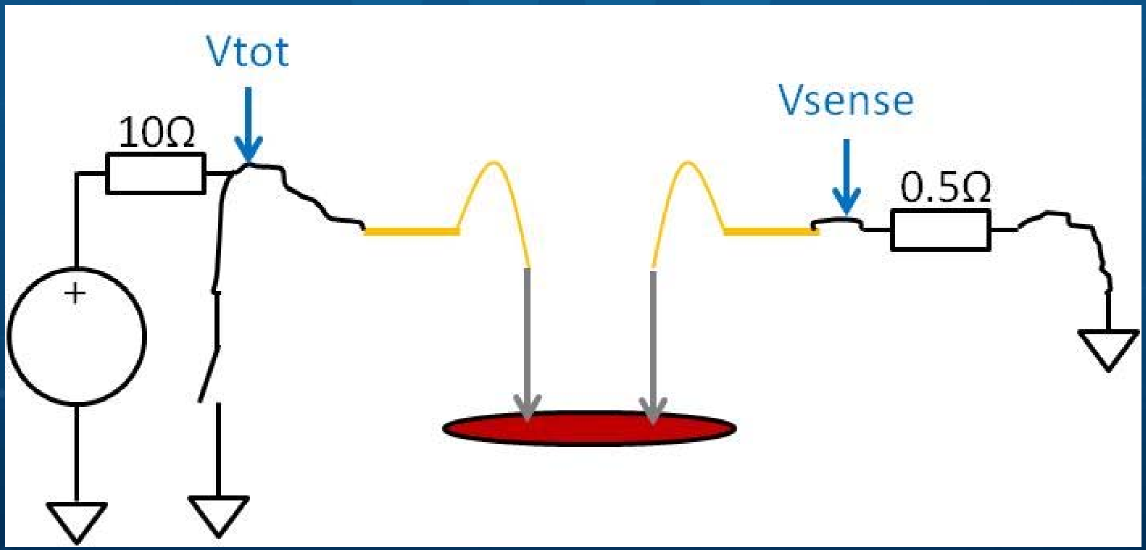
Experimental Setup

Time constant measurements

- **Vertical measurement setup schematic**

$$V_{drop} = Vtot\ - Vsense = Vdrop\ (I)$$

$$R_{probe} = \frac{V_{drop}(I)}{I} = R_{probe}(I) = R_{probe}(T, t)$$



Experimental Setup

Measurement principle and procedure

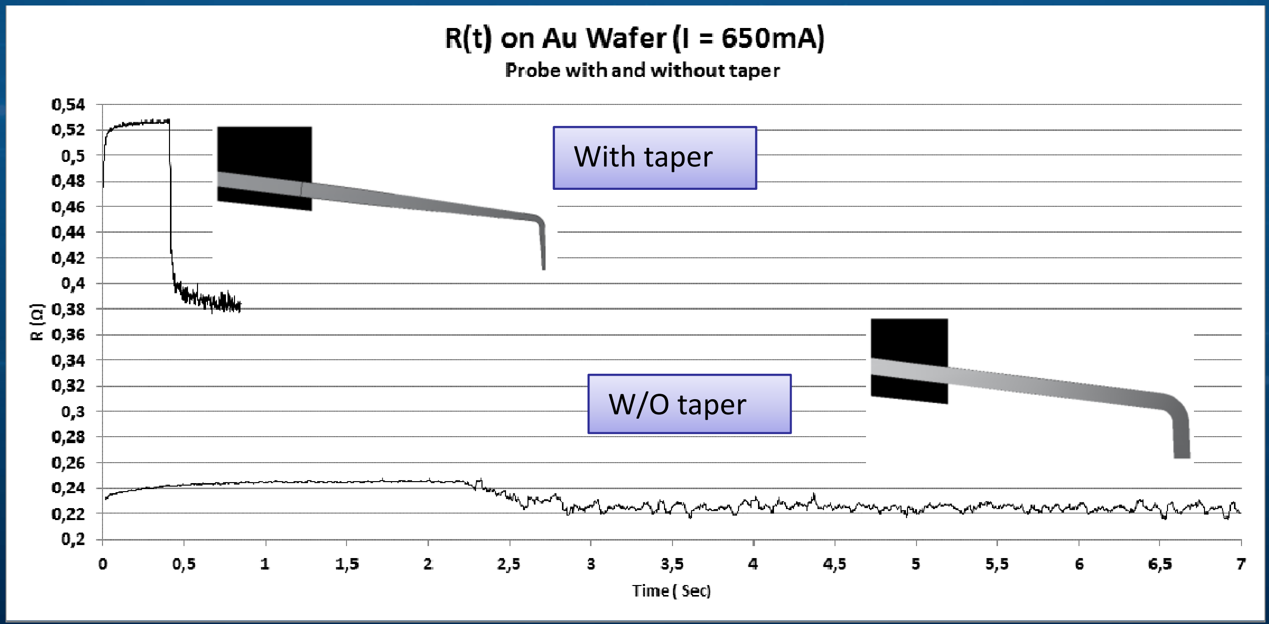
- **Measurement principle**
  - Temperature rise time constant is measured indirectly by means of probe electrical resistance measurement over time when a known current is forced to the probe under test

- **Measurement procedure:**
  - When the switch (A) is closed the power supply is in load condition and current starts to flow in the needles. An anti-bounce circuit has been connected with the switch to avoid current overshooting.
    - Current load imposed is a step.
    - The Vref (T,t) detection with a known current Iref value imposed, provides the needle raise resistance transient through the Ohm law.
  - When Switch A is opened , high current generator is disconnected from the probes and the resistance drop transient (during cooling) is measured with a 10 mA current

Experimental results

Cantilever probes

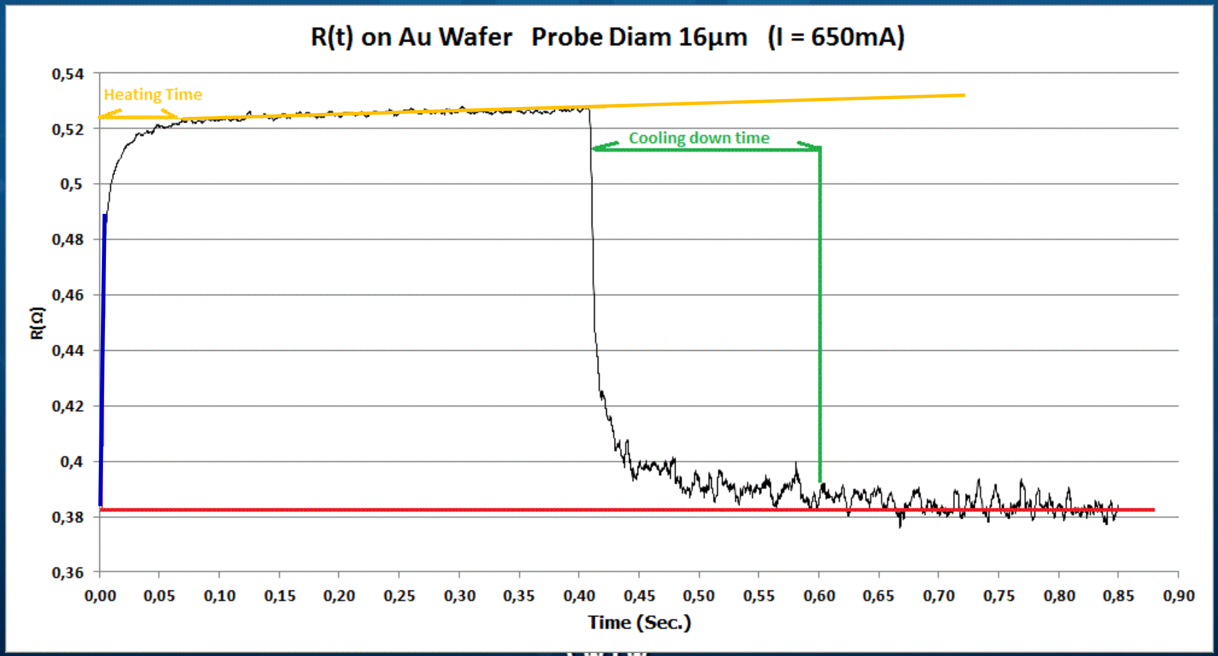
- **R(t) comparison between probes with and without taper**
  - The taper gives the greatest contribution to the R(t) variation in terms of rise time and amplitude.
  - Tip heating is in fact the main contributor of probe resistance change.



Experimental results

Cantilever probes

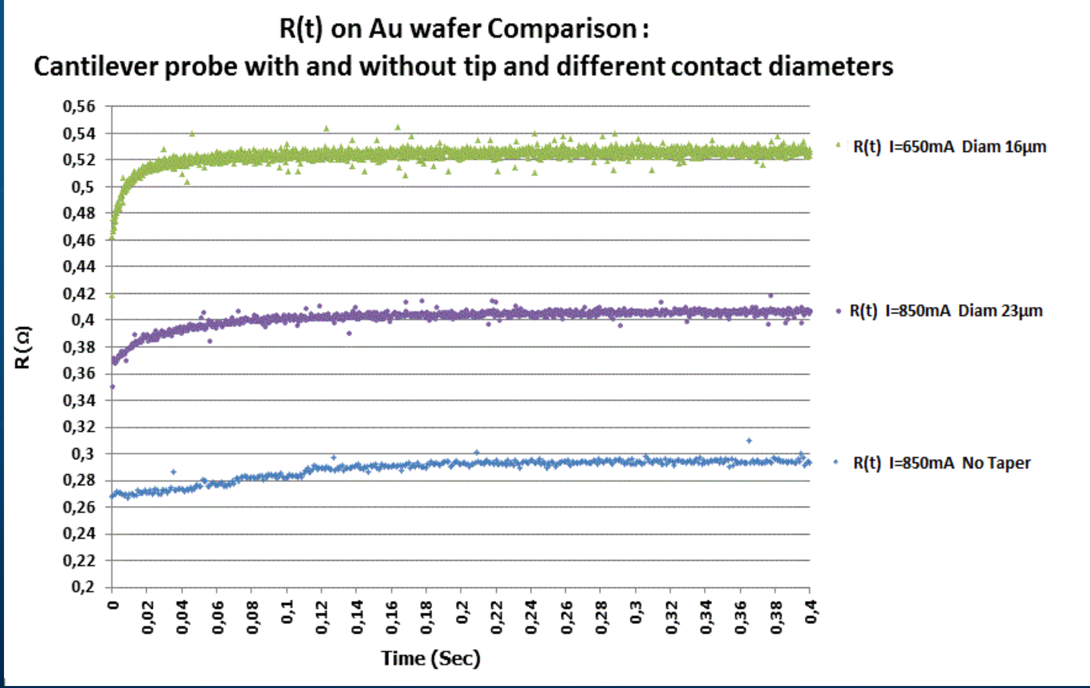
- **R(t) measurement description**
  - Blue line shows the instantaneous resistance rise (when current is applied)
  - The resistance , mainly due to the tip portion of the probe, reaches the equilibrium after about 70 ms. Further resistance increase (yellow line) is relative to the slower heating of the probe body.
  - Green line represents probe cooling down time, that is always longer than heating time.
  - Red line shows the Base Path R on Au wafer, considered as starting point for the R(t) transient.



Experimental results

Cantilever probes

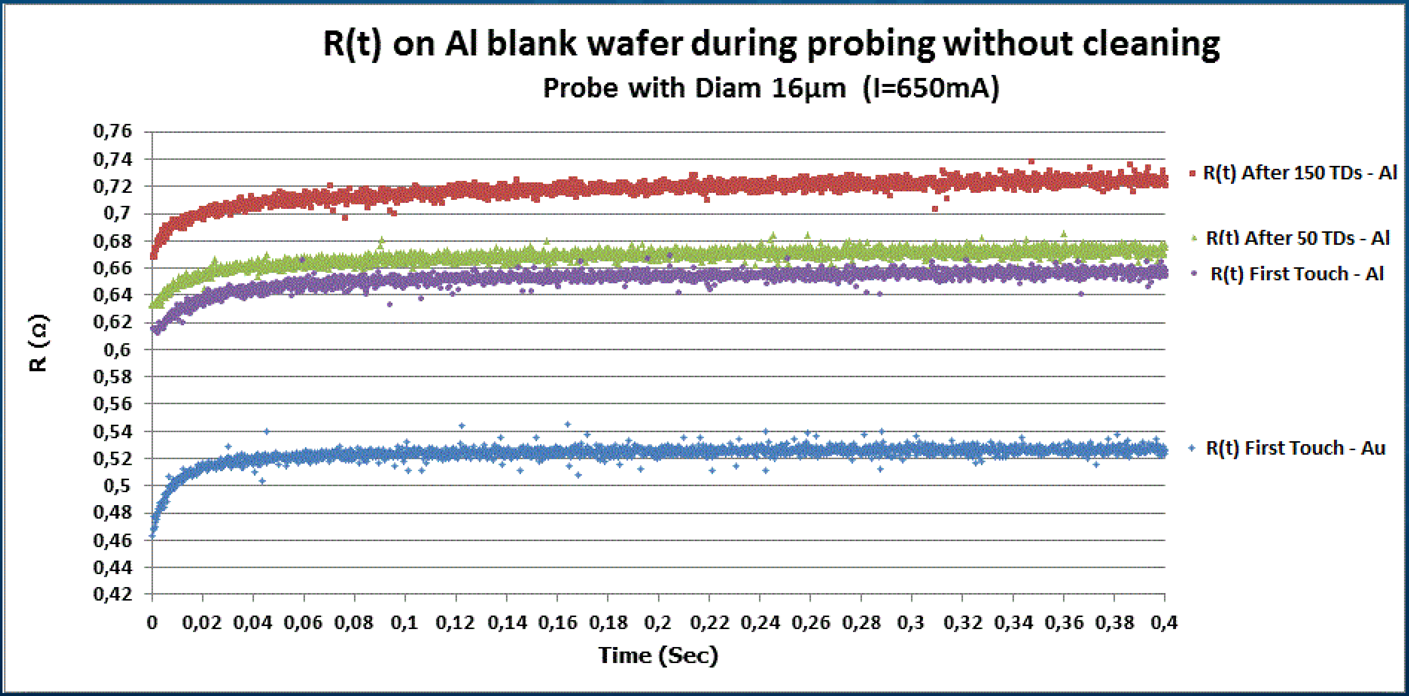
- **R(t) comparison between 2 probes with different contact diameter.**
  - The smaller the contact diameter (slimmer tip), the higher is the temperature reached by the tip that has to bear a greater current density.
  - The slimmer the tip, the faster is the transient raise time.



Experimental results

Cantilever probes

- **R(t) measurement during probing on Al Blanck wafer.**
  - Contact resistance contribution has been investigated performing many TDs on a Al blank wafer without polishing.
  - The higher the C_RES, the higher is the temperature reached by the tip and the faster is the R(t) transient.



Experimental results

Cantilever probes

- **CCC in pulsed mode (Tip discoloration)**
  - Probes with contact diameter 16 µm has been tested
  - The max current limit is establish when black Oxide (WO_2) is observed
  - 2 different pulsed current have been applied with the same Duty Cycle:

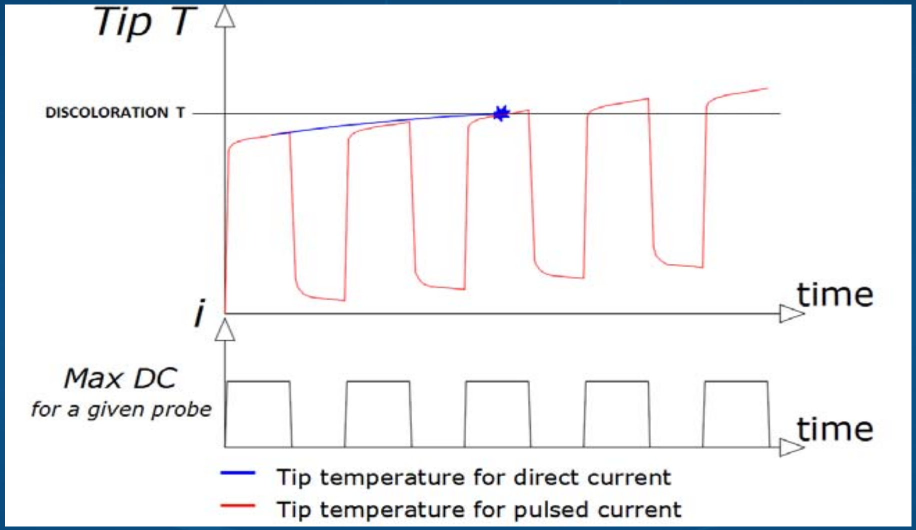
Ton	Toff	Duty Cycle	CCC
5 ms	5 ms	0,5	0,8 A
100 µs	100 µs	0,5	1 A

- **Conclusion**
  - The Duty Cycle is not enough to define Max pulsed CCC. At least t_{ON} or t_{OFF} should be considered as well.
  - t_{on} and t_{off} are relevant for the tip temperature and the oxidation speed process.
    - t_{on} is important for the max temperature reached by the tip with the consequent fast activation of the oxidation mechanism.
    - t_{off} is important for the tip cooling. A long t_{off} allows the usage of higher current than the Max CCC in continues mode and it is important in case of a train of pulse is applied.

Experimental results

Cantilever probes

- **CCC in pulsed mode**
  - Below an example of the T_{off} importance when a train of pulse are applied with a safe T_{on} for a single pulse



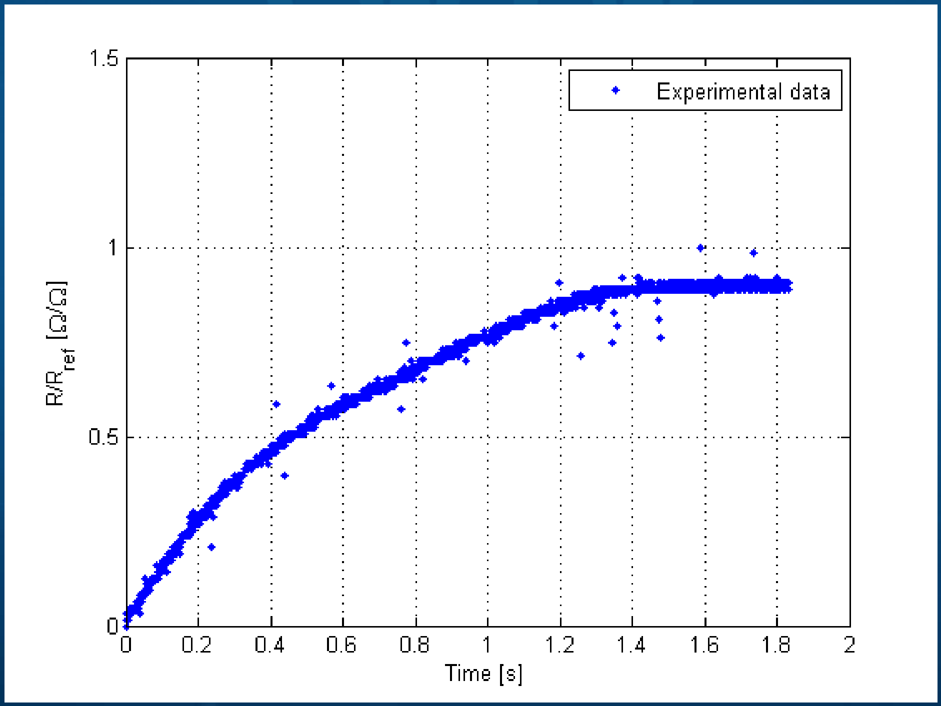
- **A visual explanation**
  - 2 video are filmed. The same current and T_{on} is applied changing only the T_{off}.
  - The current has been chosen to achieve a temperature around 2000 °C (WRe became incandescent and visible)

Video1: I=800mA T_{on}=800 ms T_{off}=300ms   Video2: I=800mA T_{on}=800 ms T_{off}=200ms

Experimental results

Vertical probe

- **In figure R(t) behavior for vertical probe is reported**
  - The transient is referred to two probes in series



Model introduction

- **Temperature dependent material properties and different boundary conditions are considered such as:**
  - Probing environment temperature, DUT temperature, temperature variation during probing (die stepping, on line cleaning, …).
  - As expected, this leads to a highly nonlinear response of the model.
- **Pulsed current working condition are studied and compared with continuous current solicitation.**
  - Duty cycle concept is adopted
  - **Needle time constant** is considered as key parameter.
- **The model has been validated since the beginning with direct measurements of needle time constant.**
  - A good agreement has been found
  - In this view, the model represents an effective tool to study probe behavior and its limit working conditions.

Model introduction

Time constant as key parameter

- **Time constant is the parameter characterizing the response to a current load**

- **It is a key parameter to evaluate the max thermal stress on a probe in relation with duty cycle and t_{ON} or t_{OFF}**

- **The pulse ton , together with pulse amplitude and duty cycle define the max temperature reached by the probe during current flow, depending on probe time constant.**

Model description

Assumptions

- **Assumptions:**
  - Time dependent temperature
  - Monodimensional heat conduction
  - Linear behavior of resistivity with temperature
  - Convective coefficient h_{conv} considered as constant

- **Convective coefficient is obtained by literature analytical/empirical formula**

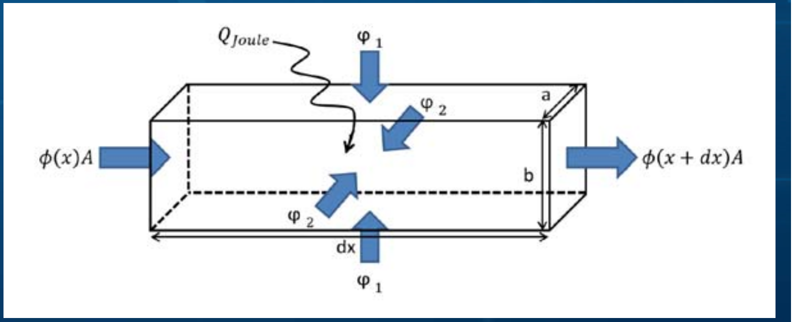
Model description

Numerical scheme

- **Numerical solution is obtained via finite difference method:**
  - Derivative of temperature versus time is approximated with a forward finite difference
  - Spatial derivative is replaced by a central finite difference approximation
  - Neumann Dirichlet boundary conditions are implemented
- **Equations used**

$$\phi = -\lambda \frac{dT}{dx} \quad \varphi = -\lambda \frac{dT}{dx} \begin{cases} \varphi_1 = h_{conv}(T_{ext} - T)adx \\ \varphi_2 = h_{conv}(T_{ext} - T)bdx \end{cases}$$

$$Q_{Joule} = dR(T)I^2 = \underbrace{\rho_0[1 + \alpha_{res}(T - T_{ref})]\frac{dx}{A}}I^2$$



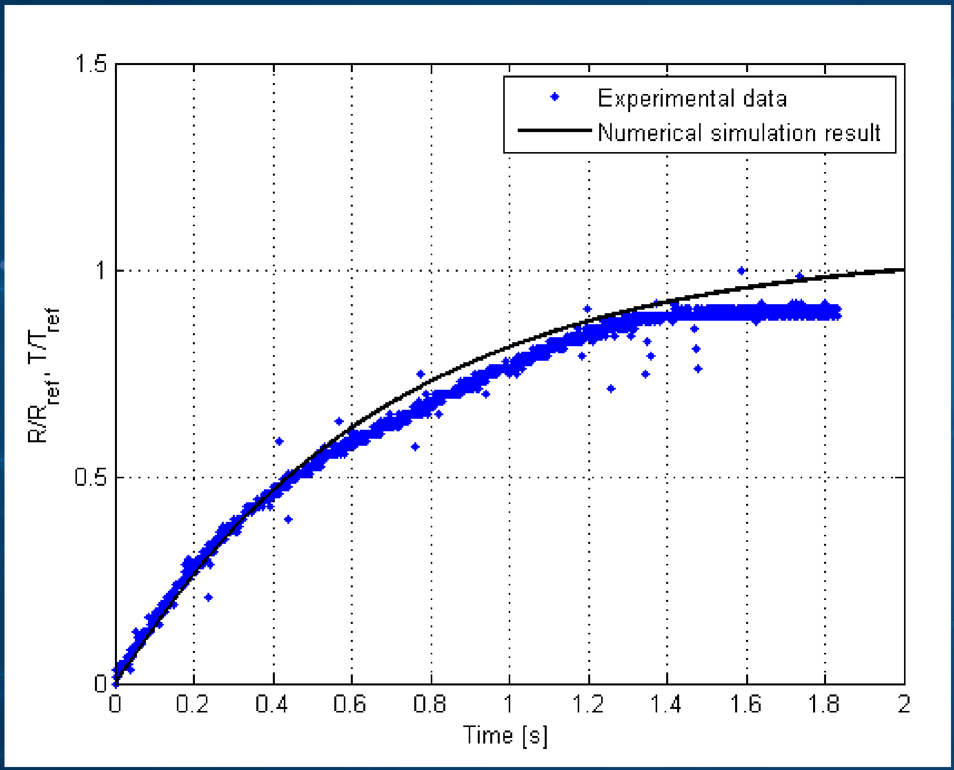
ϕ: heat flux

Model description

Main features

- **Developed code can be used to simulate thermal transient property of different needle geometry:**
  - Constant needle cross section
  - Tapered needle cross section
  - User defined needle cross section
- **It is possible to apply different time dependent current load:**
  - Pulse
  - Ramp
  - User defined analytical expression
- **Temperature boundary condition can be imposed in terms of:**
  - Constant temperature (Dirichlet BC)
  - Flux (Neumann BC)
- **It is possible to change environment temperature and the convection between needle and environment**

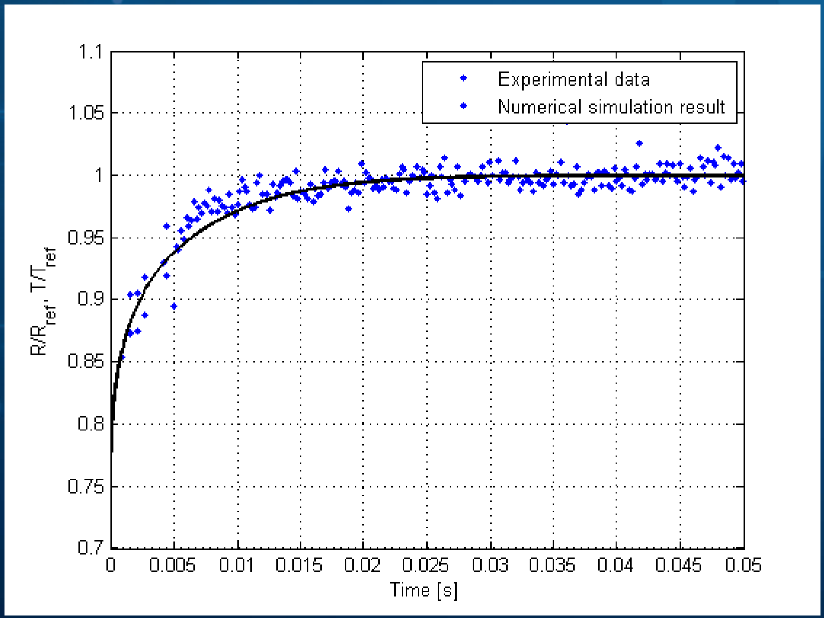
Comparison between simulation and experimental measurements

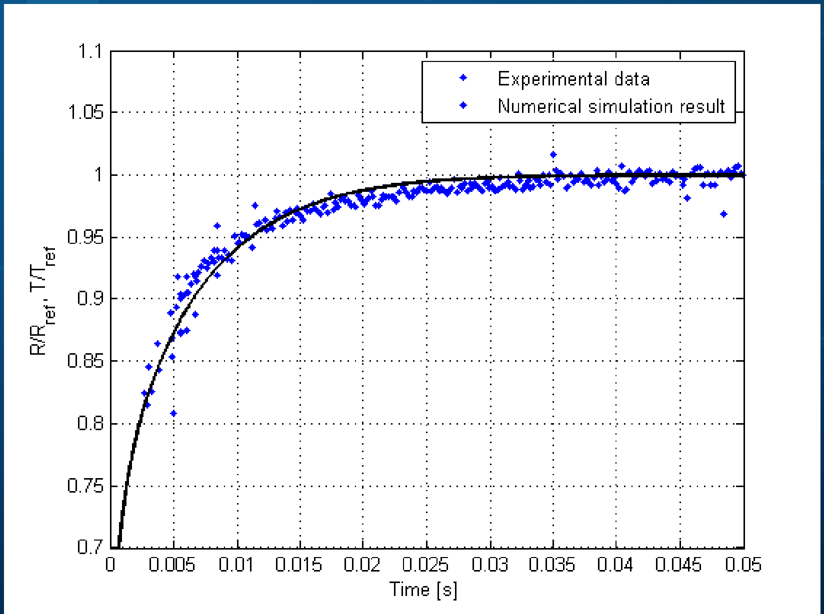


- **In figure comparison between measured data and the results provided by numerical model is showed for vertical probe:**
  - There is a good agreement between experimental data and numerical simulation.
  - Single probe needle time constant estimated is ~ 70ms
  - The error based on transient time constant is less than 10%.

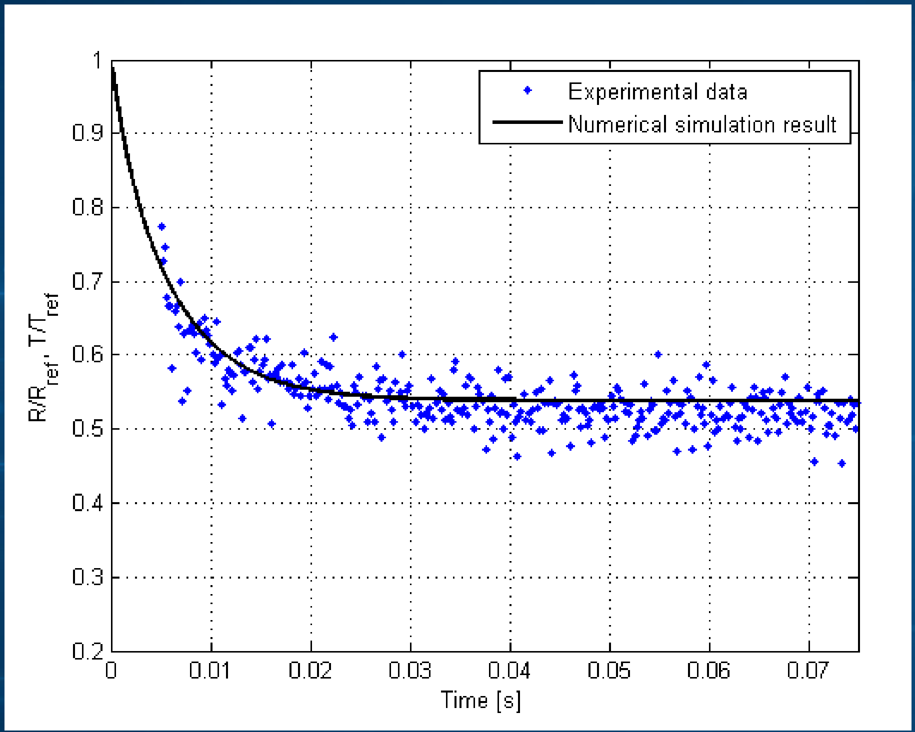
Comparison between simulation and experimental measurements

- **In figures below comparison between measured data and the results provided by numerical model is showed for cantilever :**
  - There is a good agreement between experimental data and numerical simulation.
  - The probe needle time constant estimated is about 265 µs at 400mA current load and 280 µs at 650mA current load
  - The error based on transient time constant is less than 15%.





Comparison between simulation and experimental measurements



- **In figure comparison between measured data and the results provided by numerical model is showed for catilever during the probe cooling:**
  - Probe B after 650mA current pulse
  - There is a good agreement between experimental data and numerical simulation.
  - The probe needle time constant during probe cooling is about15 ms

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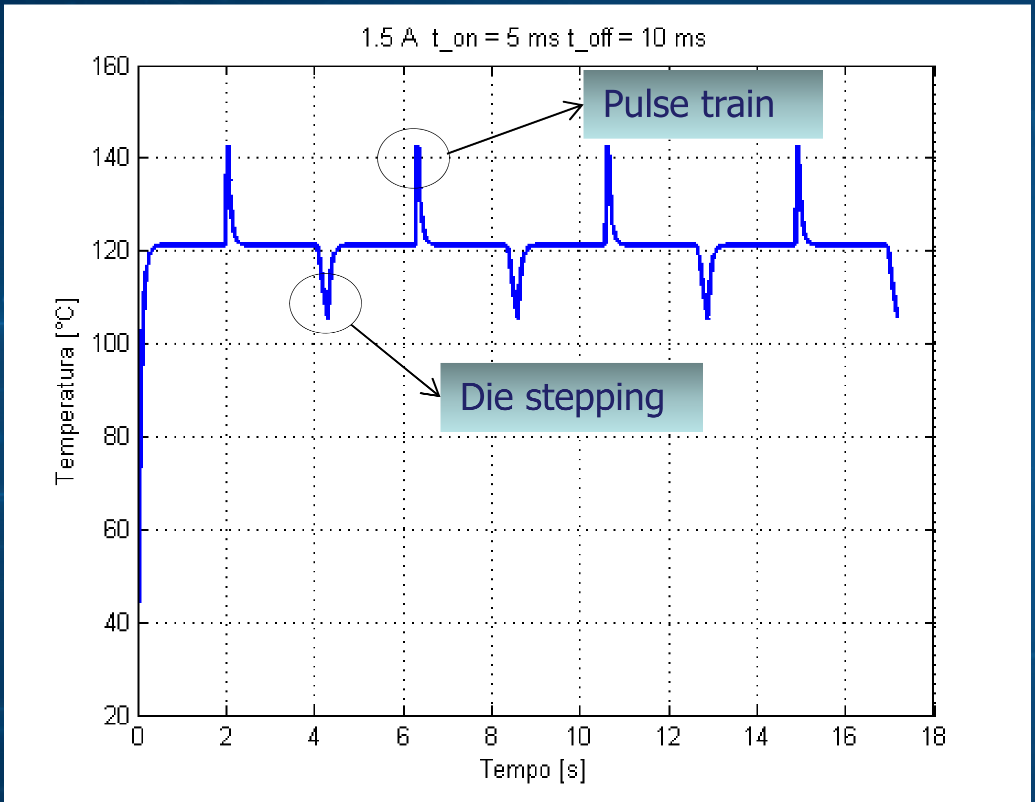
Numerical code applications

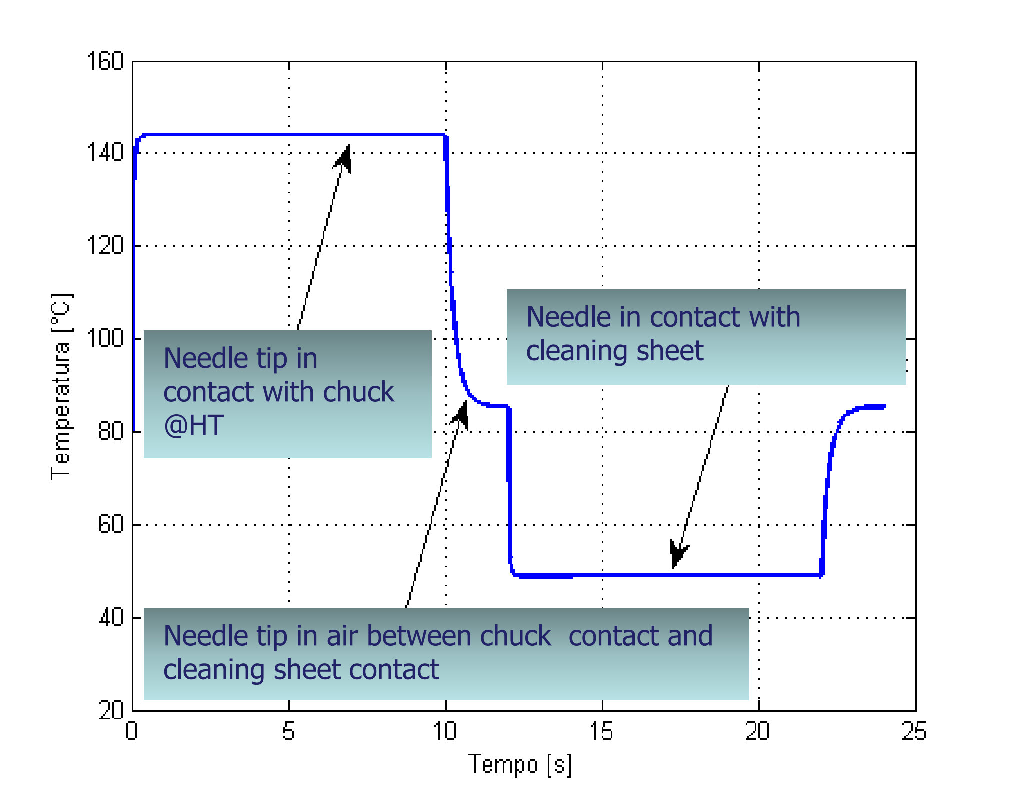
High temperature/current probing



- **In figure is reported a probing simulation with developed code:**
  - Vertical probe TPEG™ T4
  - Hight temperature probing: 150°C chuck temperature
  - Hight current: 1.5A duty cycle ton= 5ms, duty cycle toff = 10ms
- **Die stepping with the consequent needle cooling has been considered**
- **The temperature reported in ordinate is referred to the probe middle cross section**

Numerical code applications

Cleaning during high temperature probing



- **In figure is reported a second probing simulation:**
  - Thermal transient, during tip cleaning
  - High temperature probing: 150°C chuck temperature
  - Cleaning sheet temperature: 50°C
- **The temperature reported in ordinate is refered to a probe cross section near the tip**

Conclusions and further work

- **Thermo-electrical behavior of both vertical and cantilever microprobes was studied**
- **Starting from experimental measurements, a numerical model has been defined considering as key parameter the time constant**
  - Model has been validated successfully: numerical results were compared with direct measurements of needle time constant and pulsed current tests, with a good agreement.
- **The same model could be used to predict probe temperature behavior in real probing conditions considering different current and thermal loads**
  - Some examples have been reported
  - Future work will be to introduce C_RES contribution into the model and to continue model fine tuning with extensive experimental tests

Thank you !

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