Pushing Temperature Limits of High Voltage Wafer Test

Georg Franz, Rainer Gaggl
T.I.P.S. Messtechnik GmbH

Technical Innovation Physical Solution

Introduction

Power Devices

Devices switching high currents at high voltages gain increasing importance. Energy efficiency is the main driver.

Technology Transition

SiC and GaN materials have better electrical and thermal properties than silicon, enabling smaller devices with reduced losses.

SiC devices have best efficiency at medium switching frequency and very high voltage/power.

GaN devices use even higher switching frequencies allowing very compact circuitry at lower voltages.

Wafer Test Requirements

In the off-state any switching device must withstand its blocking voltage. In the on-state it must not exceed the specified conduction and switching losses.

Since properties decline with temperature, this requires wafer test at high voltage and high current - all at **maximum operating temperature**!

Technology Transition to SiC and GaN

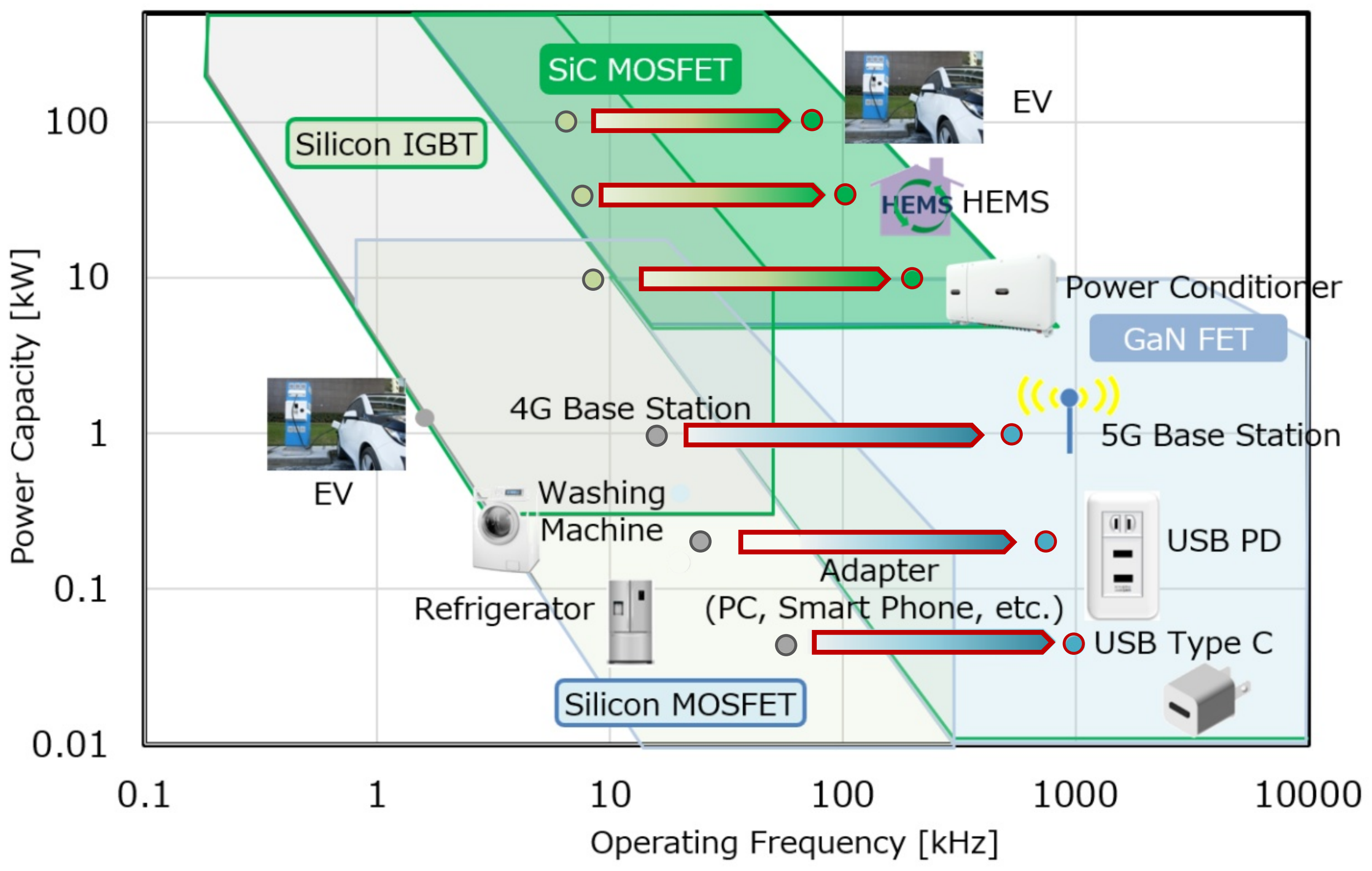
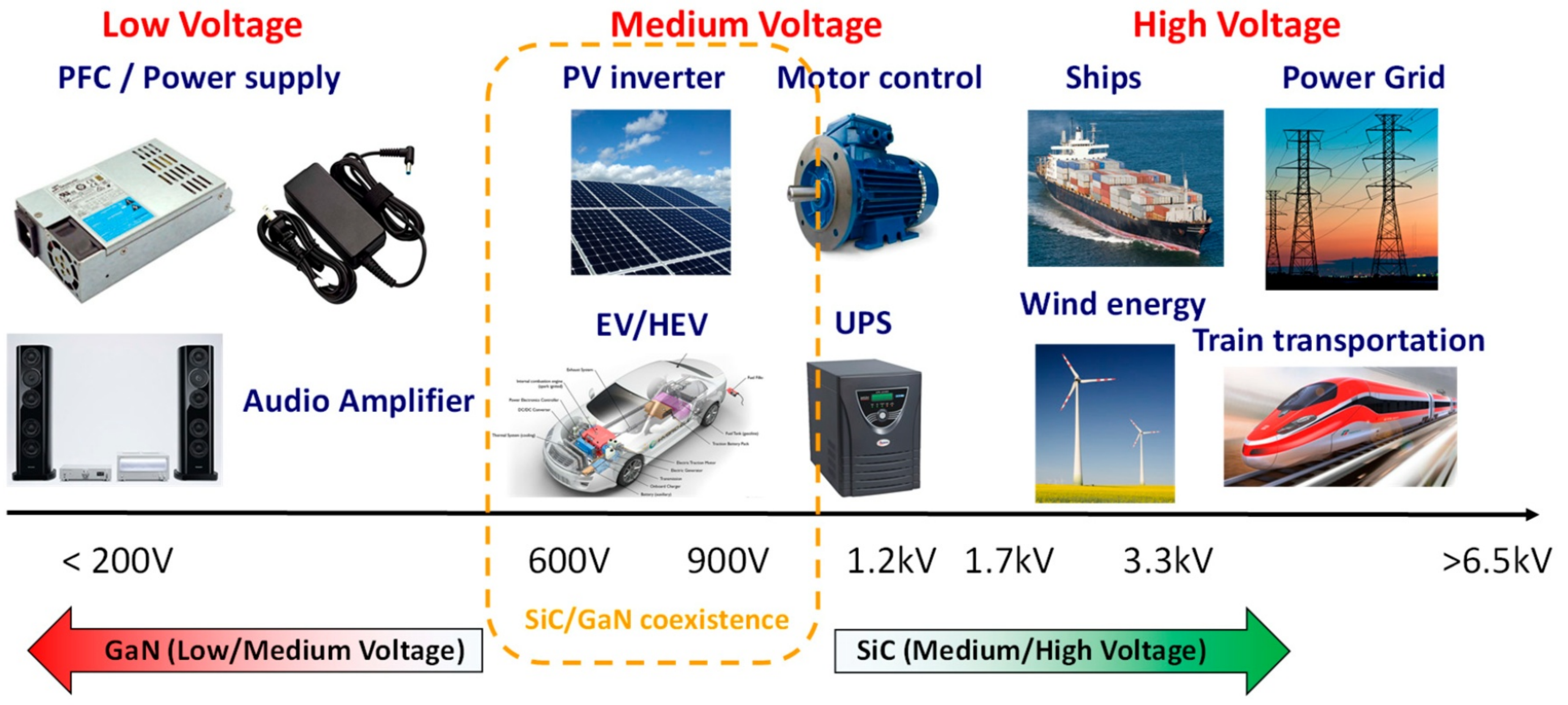


image sources:
1. Compound Semiconductors : What Are "SiC" and "GaN"?, Sanken Electric webpage;
2. An Overview of Normally-Off GaN-Based High Electron Mobility Transistors,
Fabrizio Roccaforte 1,, Giuseppe Greco 1, Patrick Fiorenza 1 and Ferdinando Iucolano, MDPI*



High Voltage Wafer Test

Technology impact on size

Higher material breakdown strength allows thinner layers for the same blocking voltage **U**.
Typical lateral dimensions are also reduced.

Considerations for wafer probing

When the test voltage is applied only on a single device, the state of neighboring devices is undefined (floating) and they may be on high or low potential.

As a result there can be high voltage between pads of neighboring dies.

Surface discharges

If the electrical field strength on the chip surface $\mathbf{E_{sf}}$ exceeds the breakdown strength of air, a flashover (arcing) can occur.

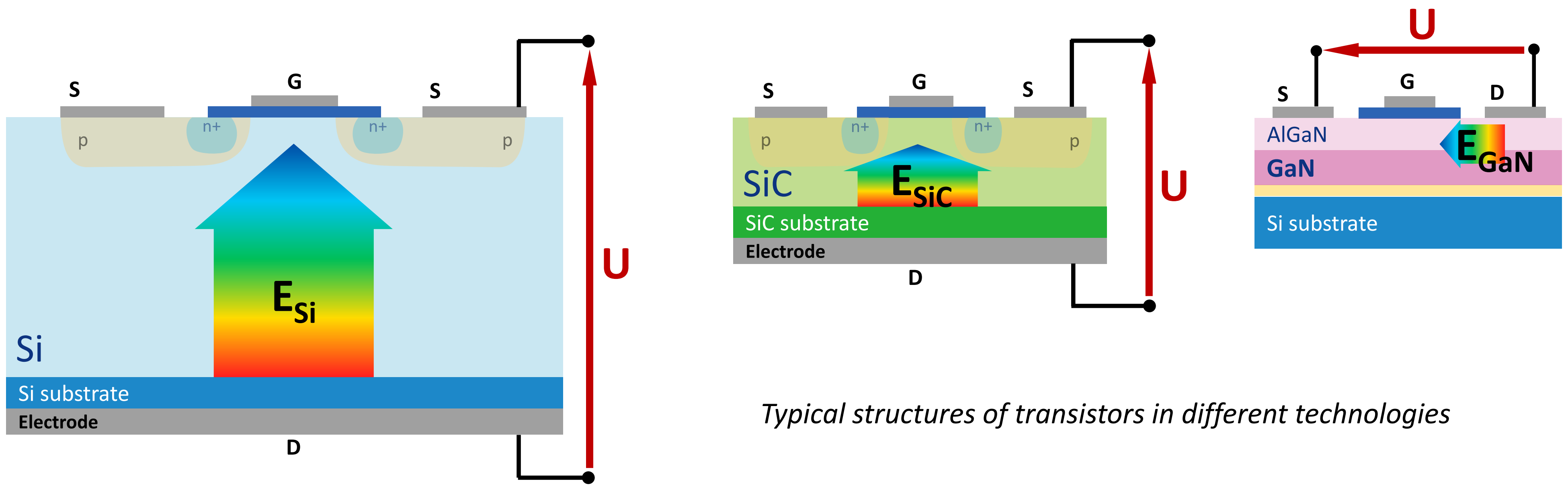
Arcing suppression

Breakdown strength of ambient air is low but increases with static pressure. Applying higher pressure above the chip surface prevents arcing.

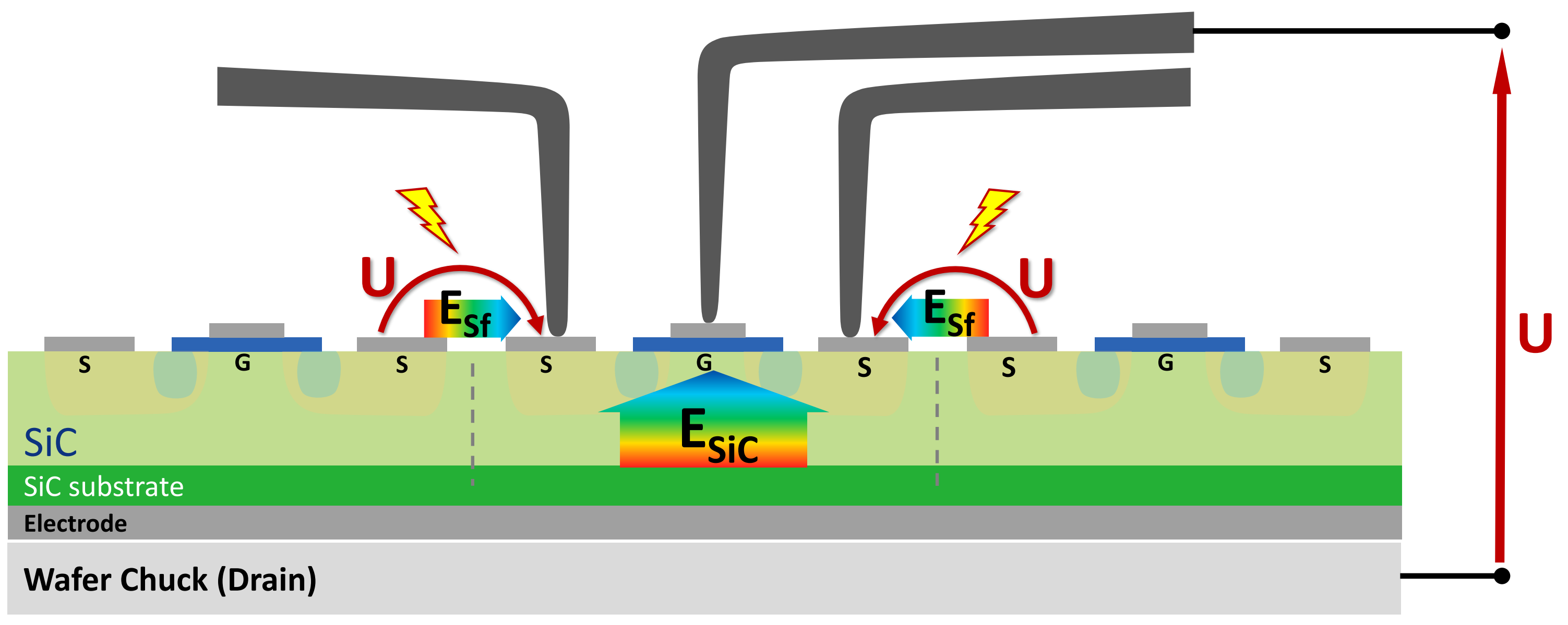
Pressure chamber

For wafer test a probe card with integrated pressure chamber is used. The chamber is slightly larger than a single chip.

Electric Field Strength (kV/mm)	Si	SiC	GaN
E_Material (Breakdown strength)	30	280	330
E_Surface (typical)	5	10	10

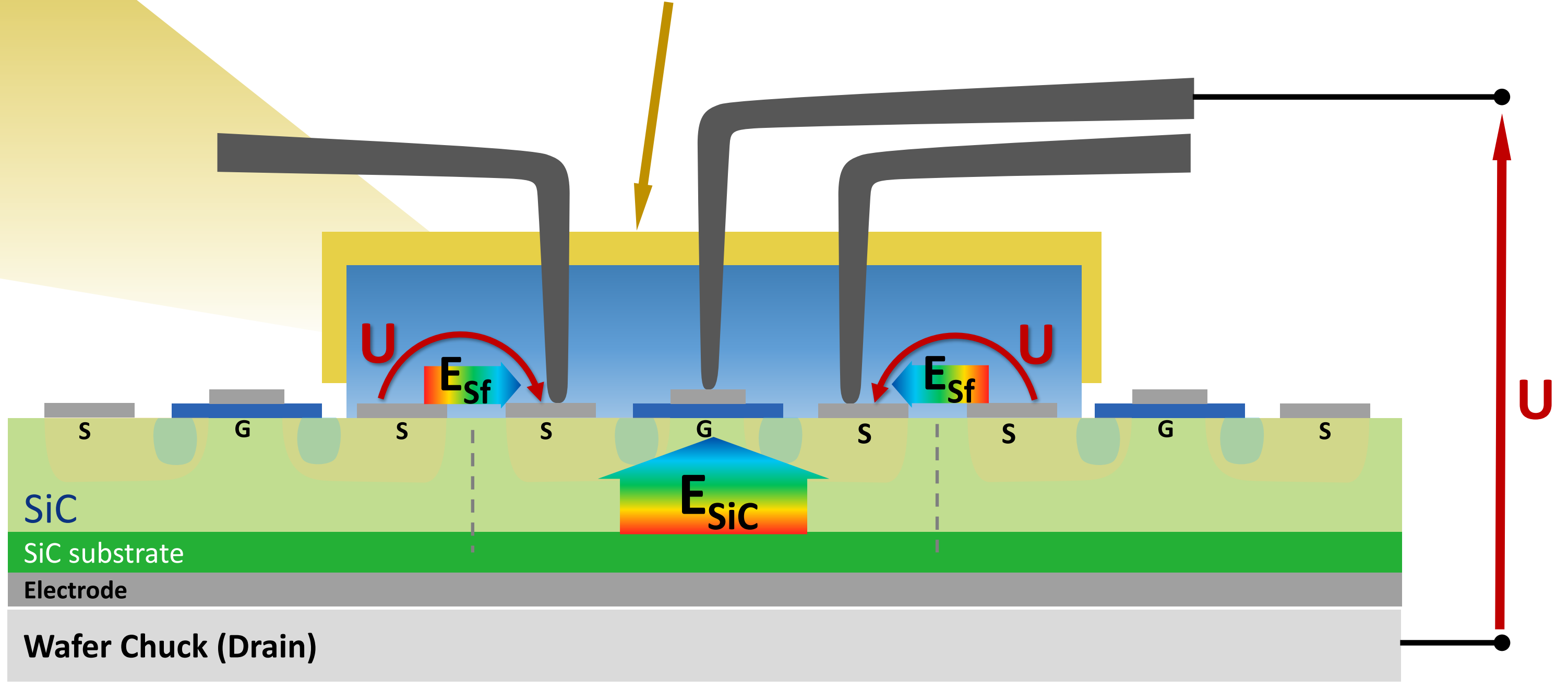


Typical structures of transistors in different technologies



Voltages between devices in wafer test

Pressure chamber



High voltage wafer test with arcing suppression

SWTest Conference 2023, June 5 to 7, 2023

Physics of air breakdown

Pressure dependency

The breakdown strength of air between infinite parallel plates can be calculated by the Paschen law as a function of pressure, voltage and gap distance.

The important fact is that breakdown strength increases with pressure. For wafer test the effective breakdown strength is slightly lower.

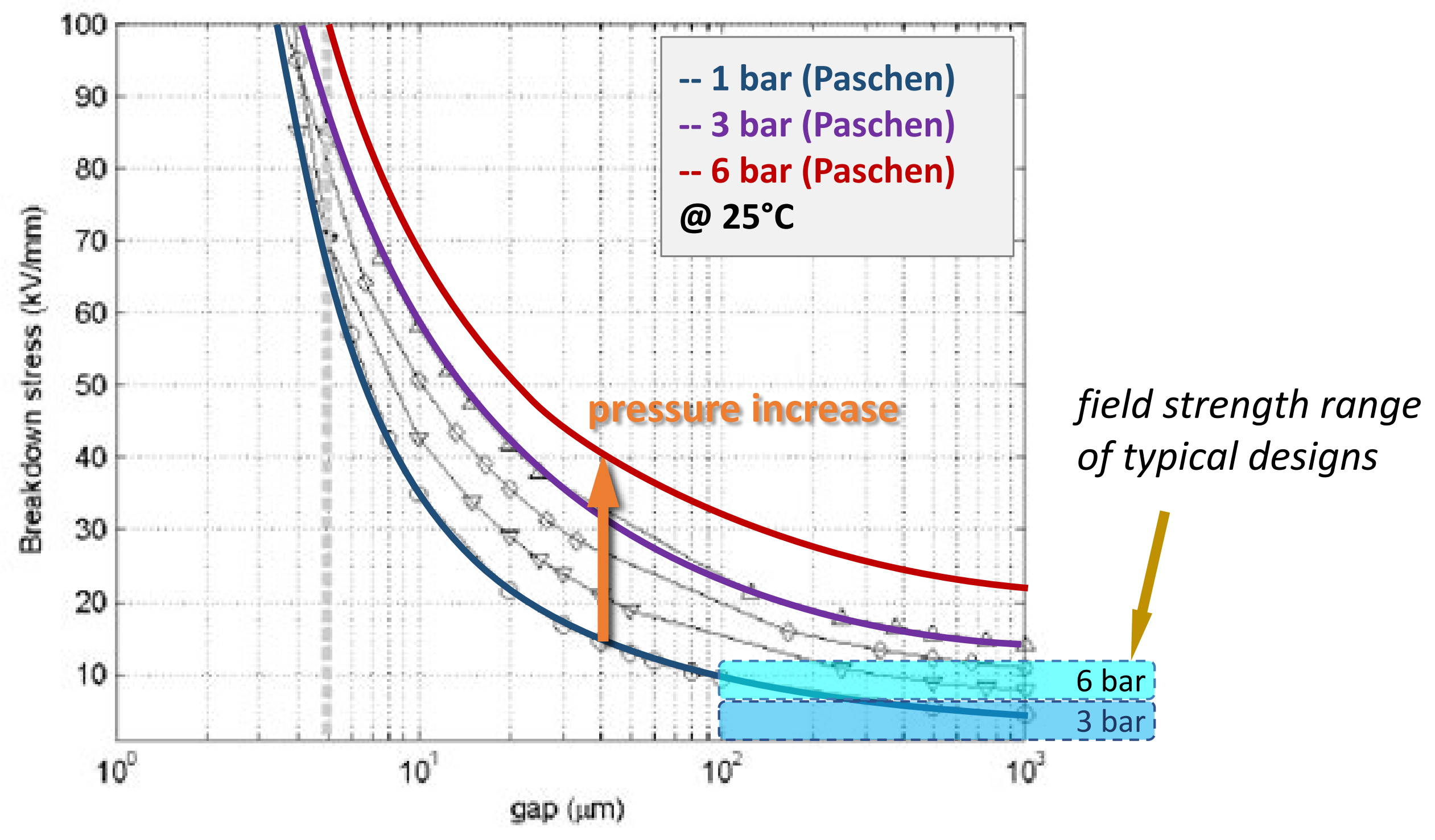
Most devices can be categorized in two groups, this is again due to the material breakdown strength. SIlicon devices usually require up to 3 bar, whereas SiC and GaN require 6 bar.

Temperature dependency

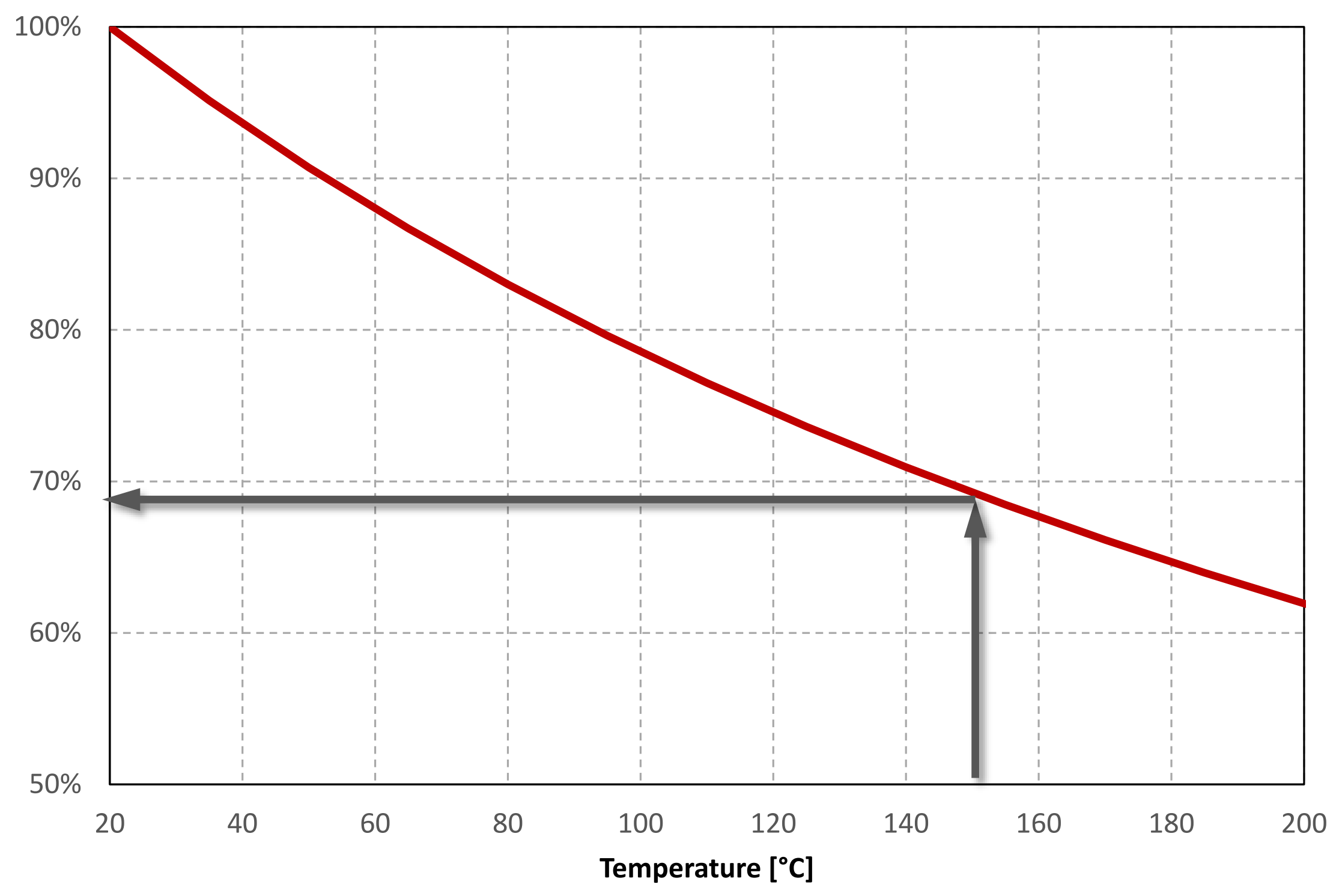
Breakdown strength is proportional to density, which decreases with temperature.

This is disadvantageous for testing at elevated temperatures. For example at 150˚ C the breakdown strength decreases to 69%. To compensate this, the pressure must be increased by 31%.

Air breakdown strength (pressure)



Air breakdown strength (temperature)



Probe Card for
High Temperature & High Voltage

Contactless pressure chamber

The chamber has a freely movable seal ring that can follow the vertical chuck motion.

This seal is hovering over the wafer surface at a constant distance of several micron.

Seal rings are made in various sizes to adapt to die sizes.

Compressed air flow

There is a constant flow of compressed air through the chamber that exhausts through the small gap between seal and wafer. The air is fed through an adapter on top of the probe card.

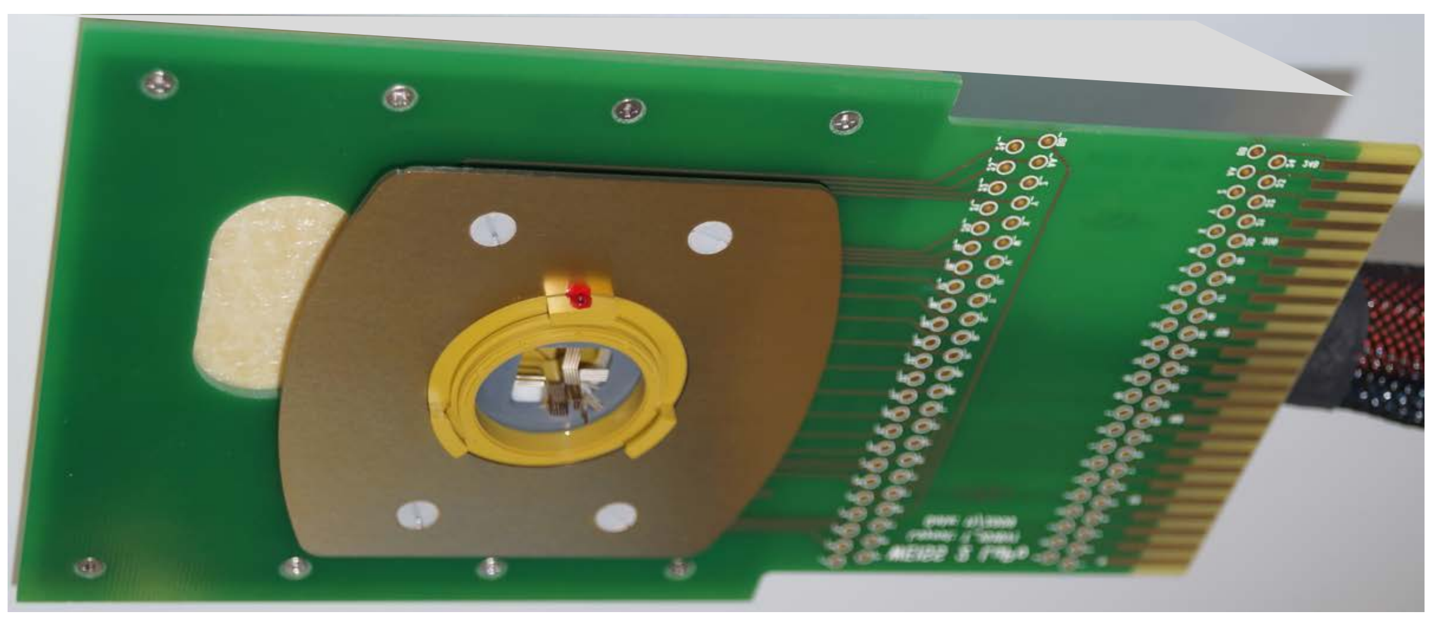
Probe card active cooling

To keep the cantilever probe tips at reasonably stable positions and maintaining structural integrity, active air cooling is used.

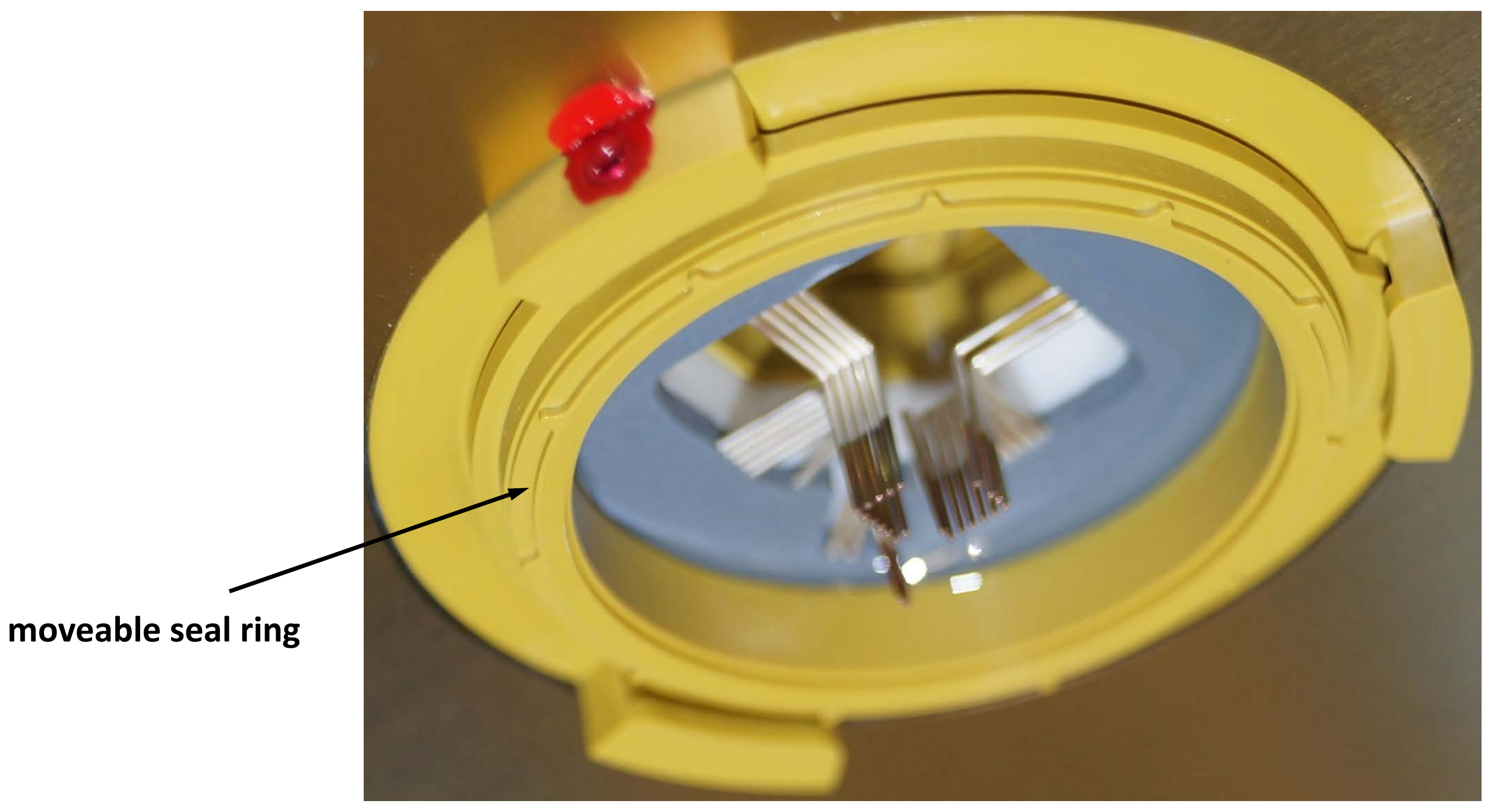
A concentric stream of compressed air at ambient temperature flows through the probe card and needle spider and exits radially on bottom of the probe card PCB.

Thermal equilibrium

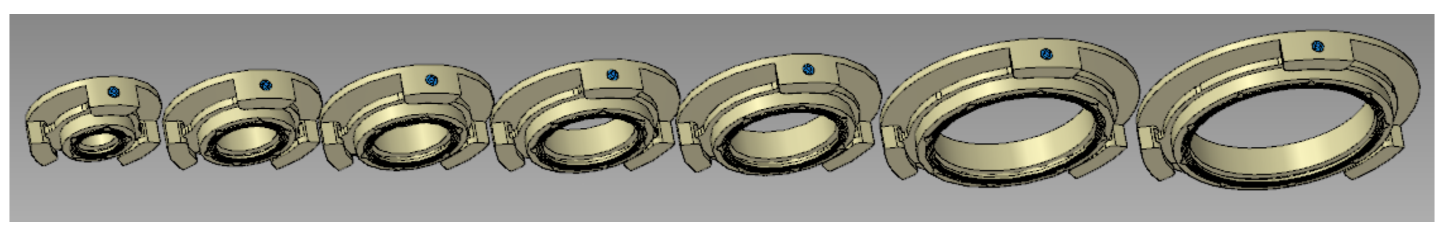
By heating the wafer from both sides any temperature gradient near the device under test can be avoided. Absolute temperature accuracy and stability of +/-2˚ C can be achieved for the device under test.



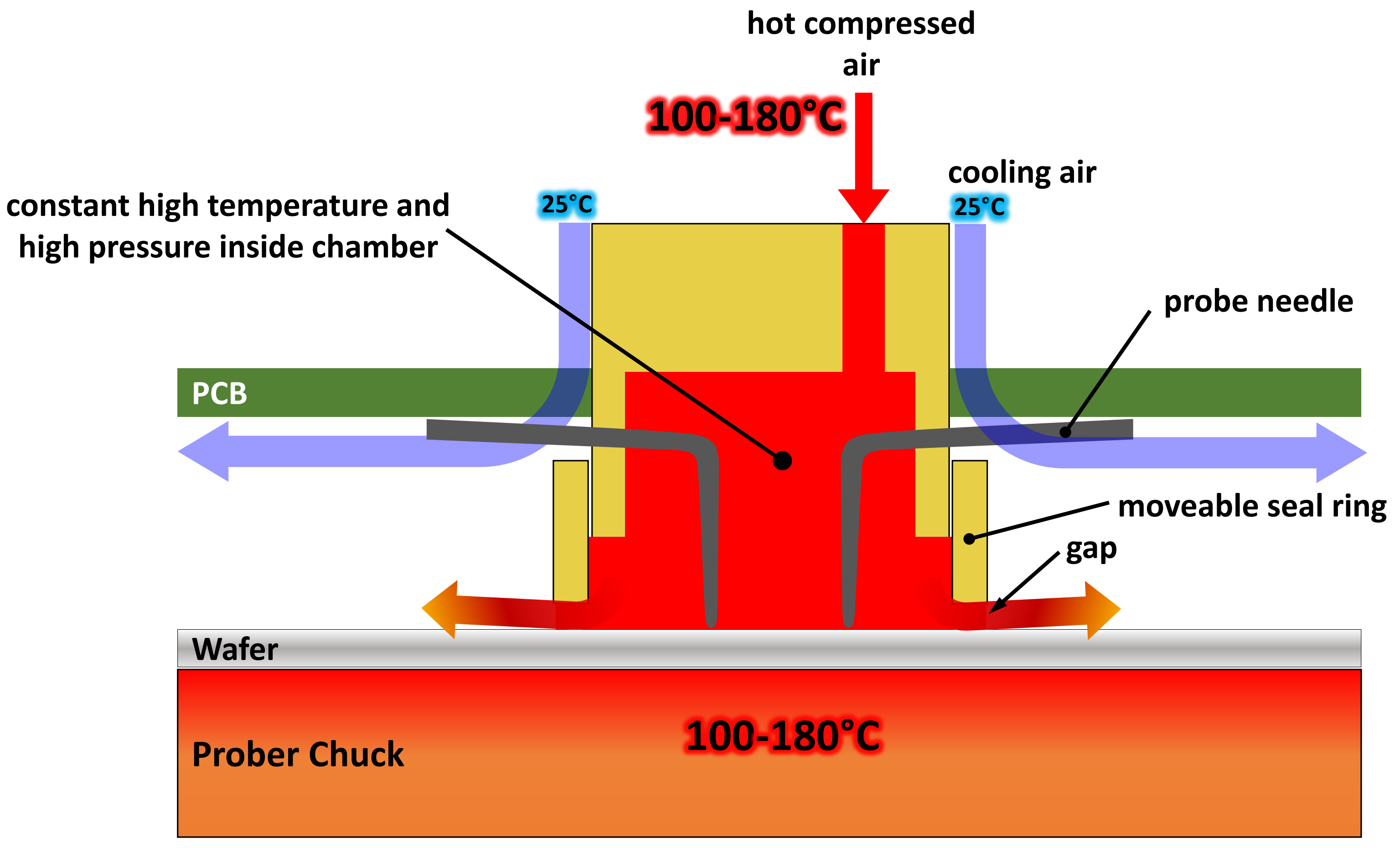
Probe card – bottom view with pressure chamber



Pressure chamber – moveable seal ring and probe tips



Various chamber sizes



Probe card – schematic cross section of hot air pressure chamber

Media Heater for HV-HT probing

Concept of operation

The media heater can be used with any inert gas (usually air or nitrogen). It turns on the heater if gas flow through the probe card is detected. When the internal controller measures a temperature within the tolerance band, the prober gets a start signal.

Media heater hardware

The main unit contains an electric heater featuring a cascaded temperature controller for fast ramp-up, stable operation and fast recovery after short test interruptions (when gas is turned off).

Media adapter

The media adapter is screwed down on the probe card. It has a built-in thermocouple that measures the hot air temperature. The hose assembly is pluggable at the back of the main unit.

Controller interface

Only target temperature and tolerance band need to be set. The actual temperature can be watched on the small graphical display or via the Modbus over Ethernet interface.

Performance parameters

The heater can handle up to 175 Nl/min mass flow at up to 8 barg and a maximum temperature of 180° C.

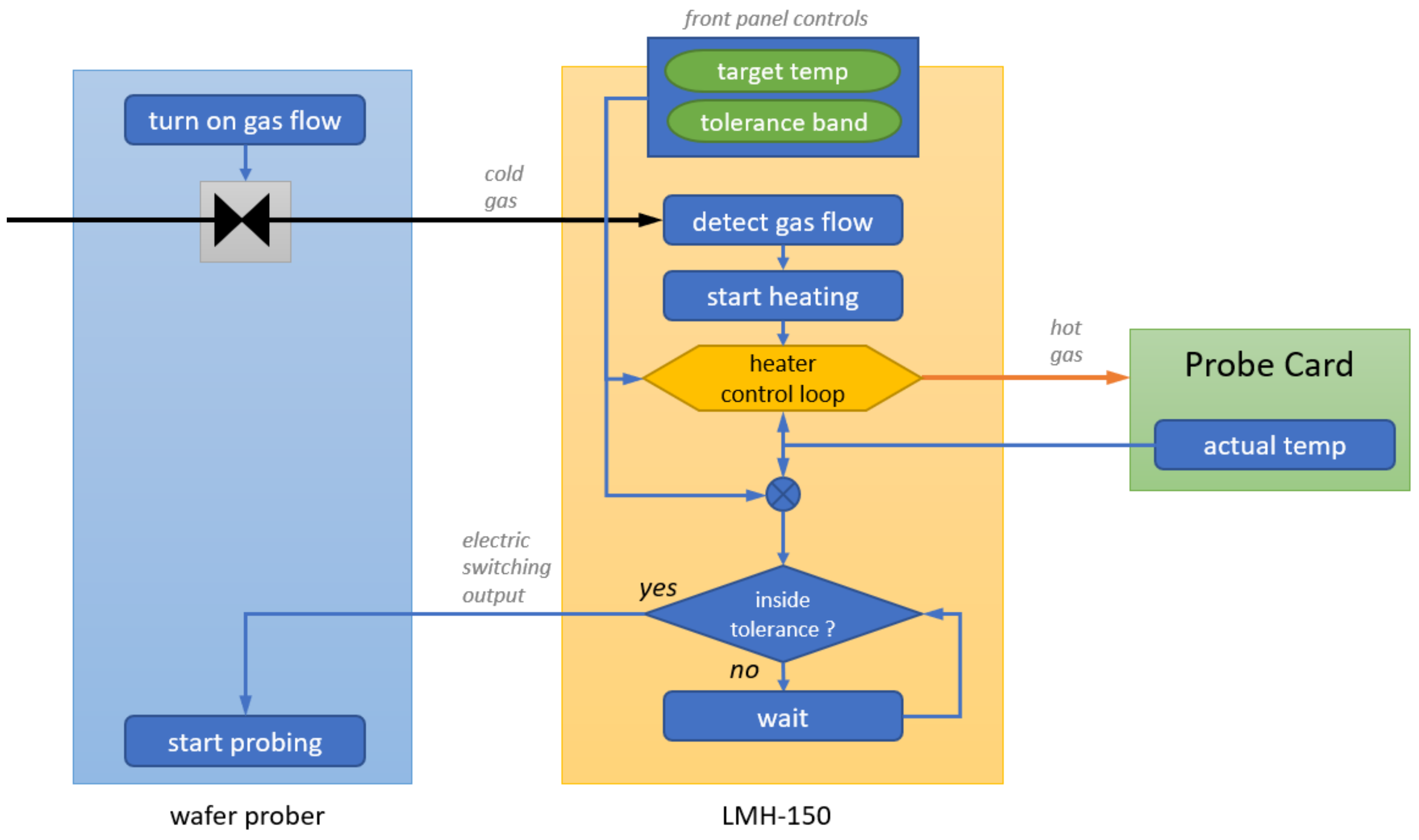
The warm-up time from cold is less than 3 minutes.

Temperature accuracy for the hot air stream is +/-1.5° C. Settling times of <30 seconds can be expected after short interruptions.

Temperature Limits

The hot air probe system was tested and qualified for prolonged 180° C operation.

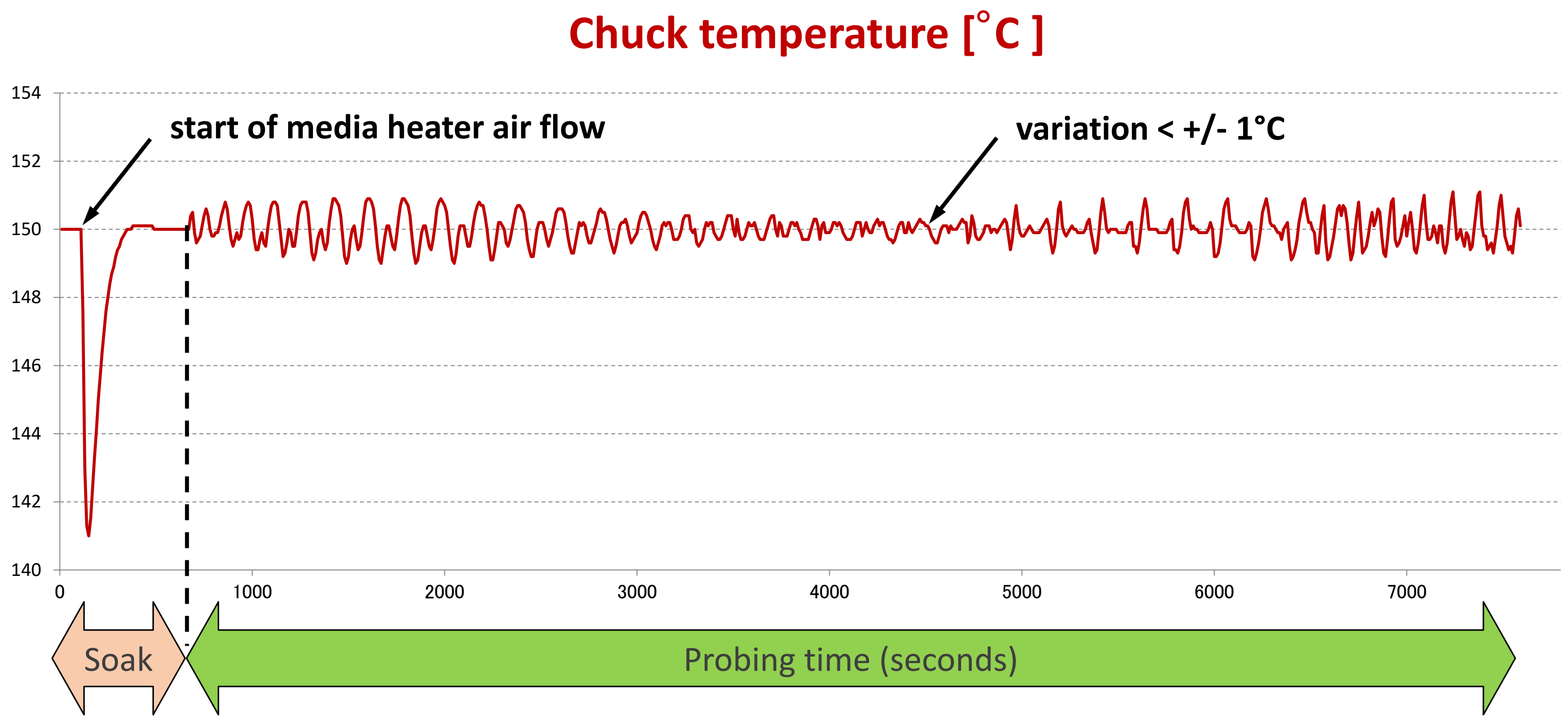
Pushing towards even higher temperatures will encounter hard to overcome limits on several frontiers, including mainly materials but also physics (pressure rise for temperature compensation).



Connection scheme for wafer prober and media heater

Media heater unit with hose assembly / adpter and probe card

Temperature display (orange trace: probe card, red trace: heater)



Measured chuck temperature deviation while probing with hot air flow on

Conclusion

Results and Performance

Temperatures for high voltage wafer test could be successfully raised from 125° C to 150° C and lately to 180° C with good stability. However applications that require high pressure already at ambient temperature can still run into supply or operating limits before reaching the target.

Limitations and Outlook

Currently our cantilever probe card technology and the media heater are limited to a maximum operating temperature of 180° C, with ongoing research towards 200° C.

Contact

In case of questions or for additional information please conatct:

Mr. Georg FRANZ
T.I.P.S. Messtechnik GmbH
g.franz@tips.co.at
+43 4242 319 720 19