IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

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“Sparking” Challenges: AC high voltage wafer test

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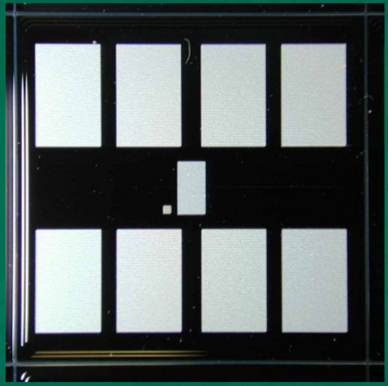
Overview

- **Devices under test**
  - Power switches (IGBT, MOSFET, Diodes; Si, SiC, GaN,...)
  - High voltage communication devices
  - ...
- **Test requirements**
  - AC wafer level testing up to 10kV
  - low current
  - 50/60 Hz
- **Test limitations**
  - Flash-over strength of probe card / DUT
  - Voltage, pressure, device geometry



IGBT

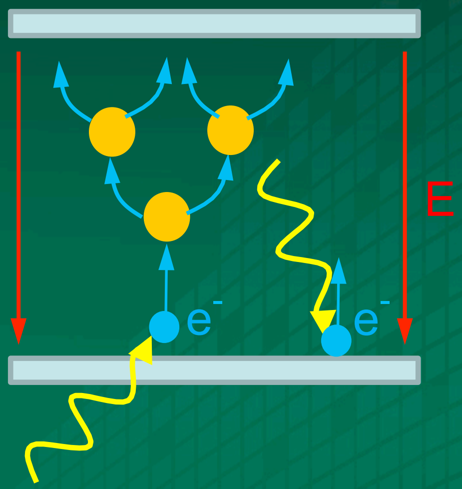
Objectives

- **Outline Flash-over theory**
  - Gas discharge mechanisms
  - Voltage strength vs. pressure
  - Field homogeneity
  - Surface discharges
- **Characterize limitations of test equipment**
  - Measured voltage strength
  - Predictability of voltage strength
- **Guidelines for probe card design (T.I.P.S.) Recommendations for test development**
  - Safe flash-over distances
  - Considerations for AC test design

Flash-over theory

Generation mechanism

- **Start condition**
  - Presence of start electron
  - Ionization by UV light/cosmic radiation
  - Stochastic nature

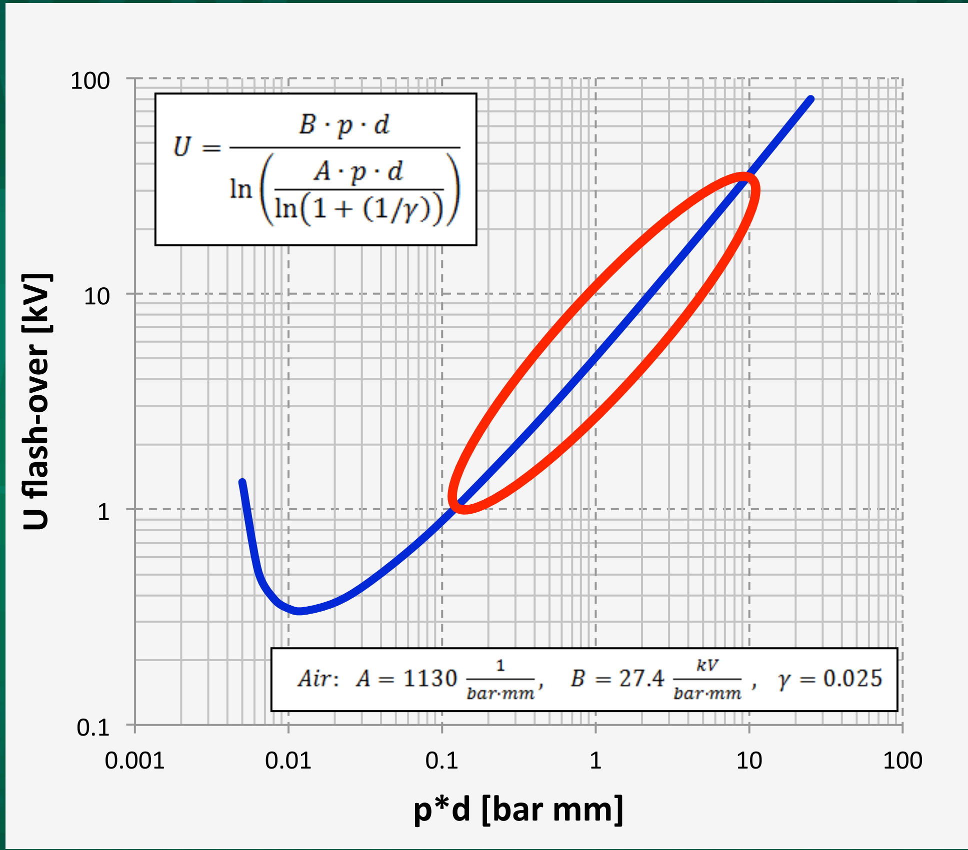


- **Electron avalanche**
  - Electron accelerated to ionization energy
  - Collision → new electrons → avalanche
  - Recombination → photons → new start electron on cathode

- **Self-sustaining discharge if**
  - More new electrons than recombinations
  - Every avalanche triggers at least one new = Ignition condition

Paschen law

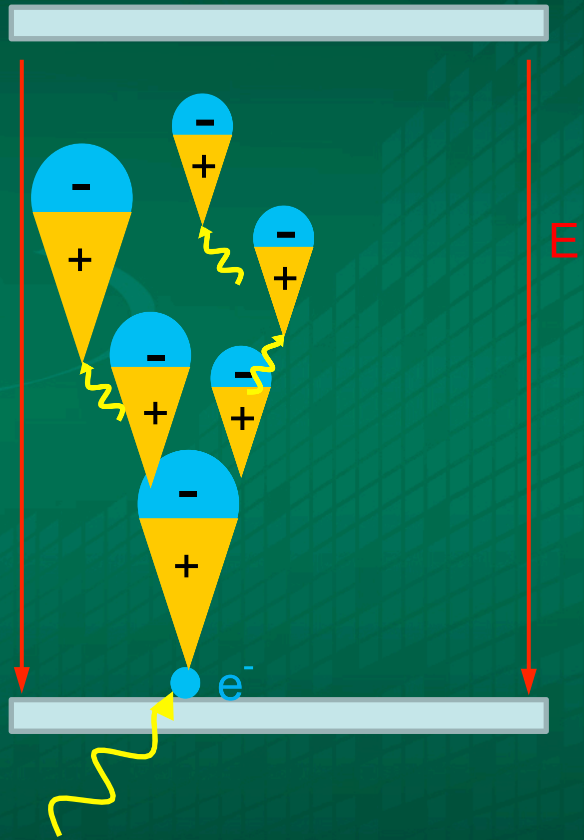
- **Empirical**
  - Homogenous field
  - Function of (p*d)
  - depends on gas type
  - electrode material
- **Use**
  - General behavior
  - Estimate pressure
- **Applicability**
  - Limited (homogeneity)
  - No data for common probe materials



Flash-over theory

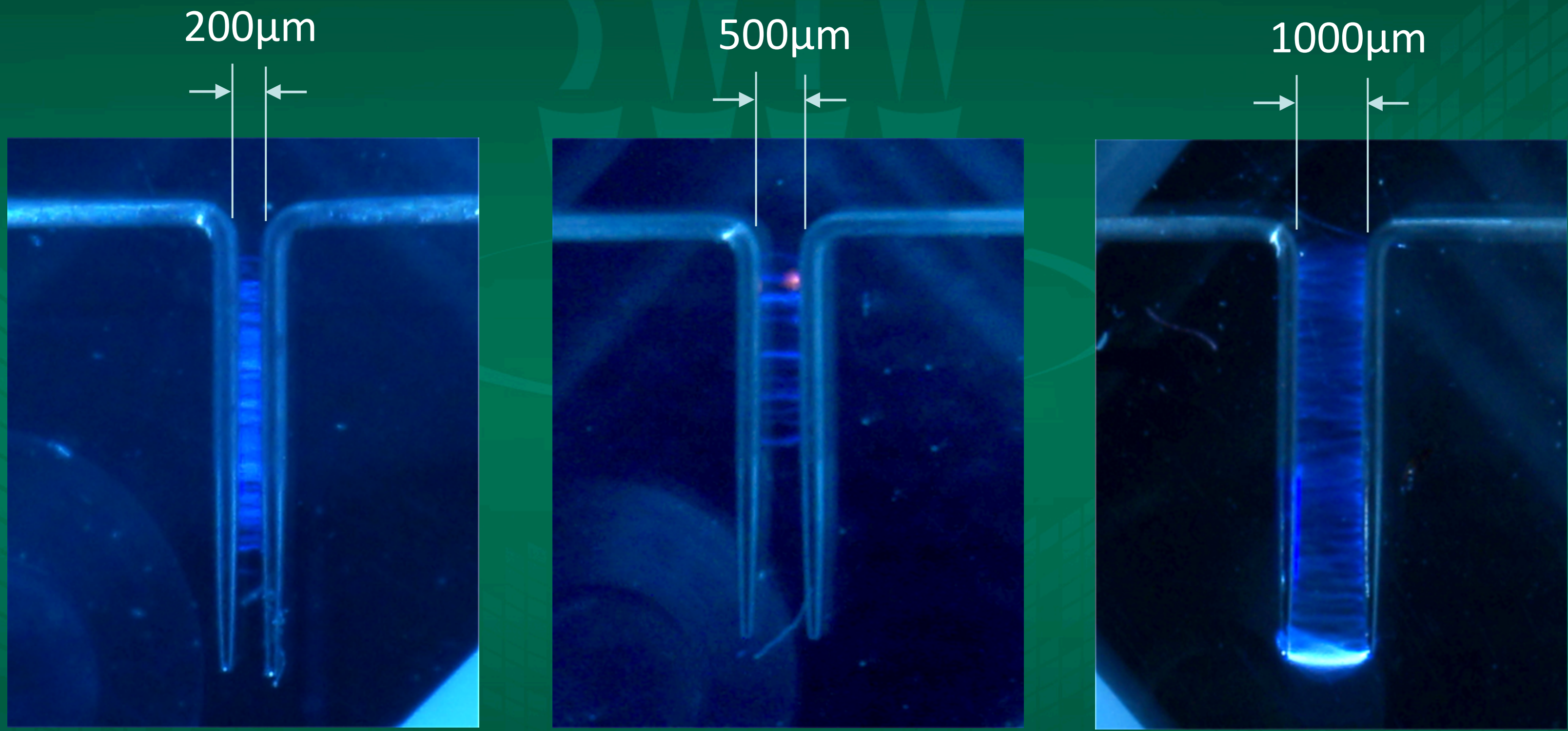
Streamer mechanism

- **Streamer**
  - Start in high field strength
  - Fast growth (during one avalanche)
  - Can traverse low field regions
  - Self propagating
- **Space charge**
  - Ions slower than electrons
  - Electron cloud
  - Electric field enhancement



Flash-over: atmospheric pressure

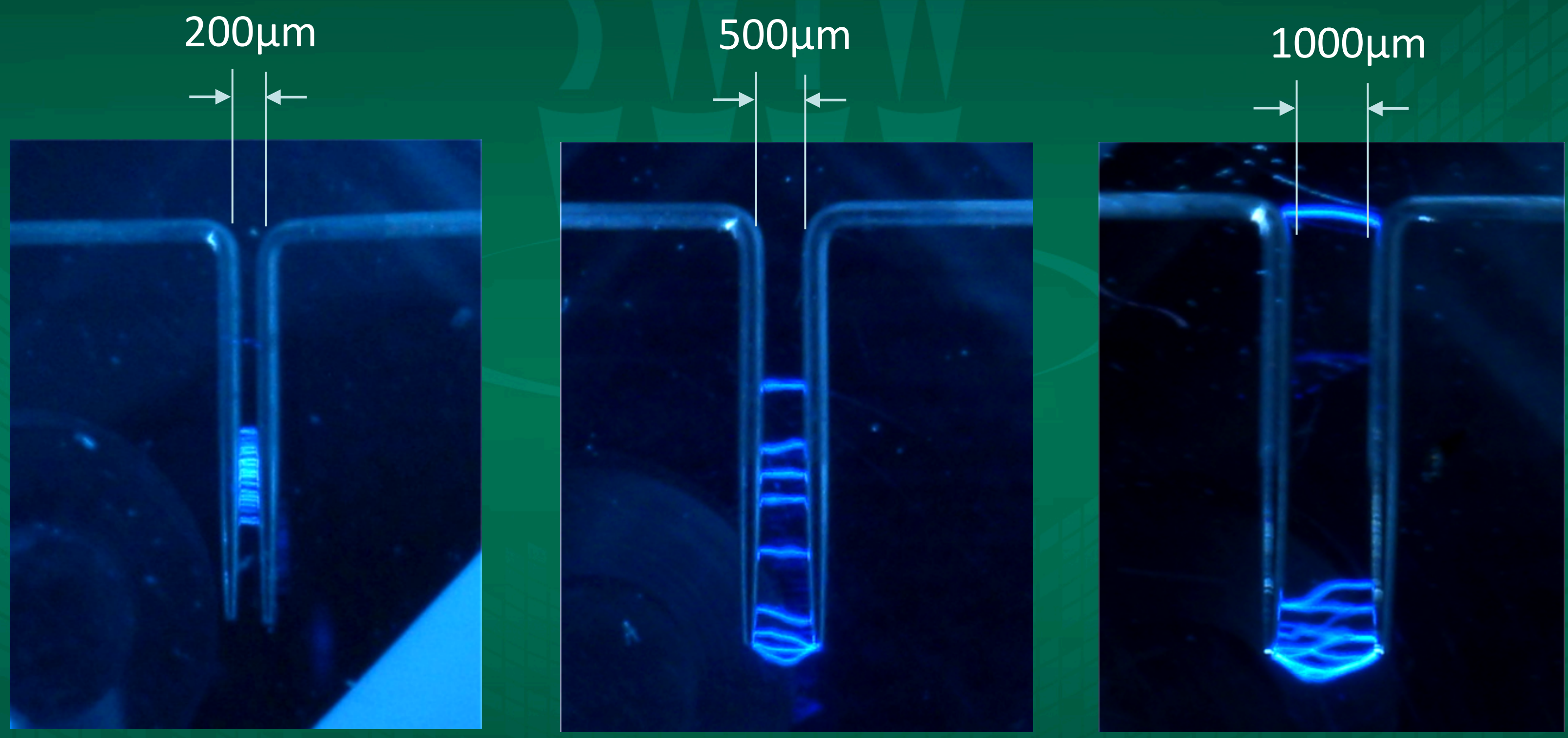
p = 1 bar absolute



randomly distributed streamers:
many short (nanosecond) discharges, UV emission, not audible

Flash-over medium pressure

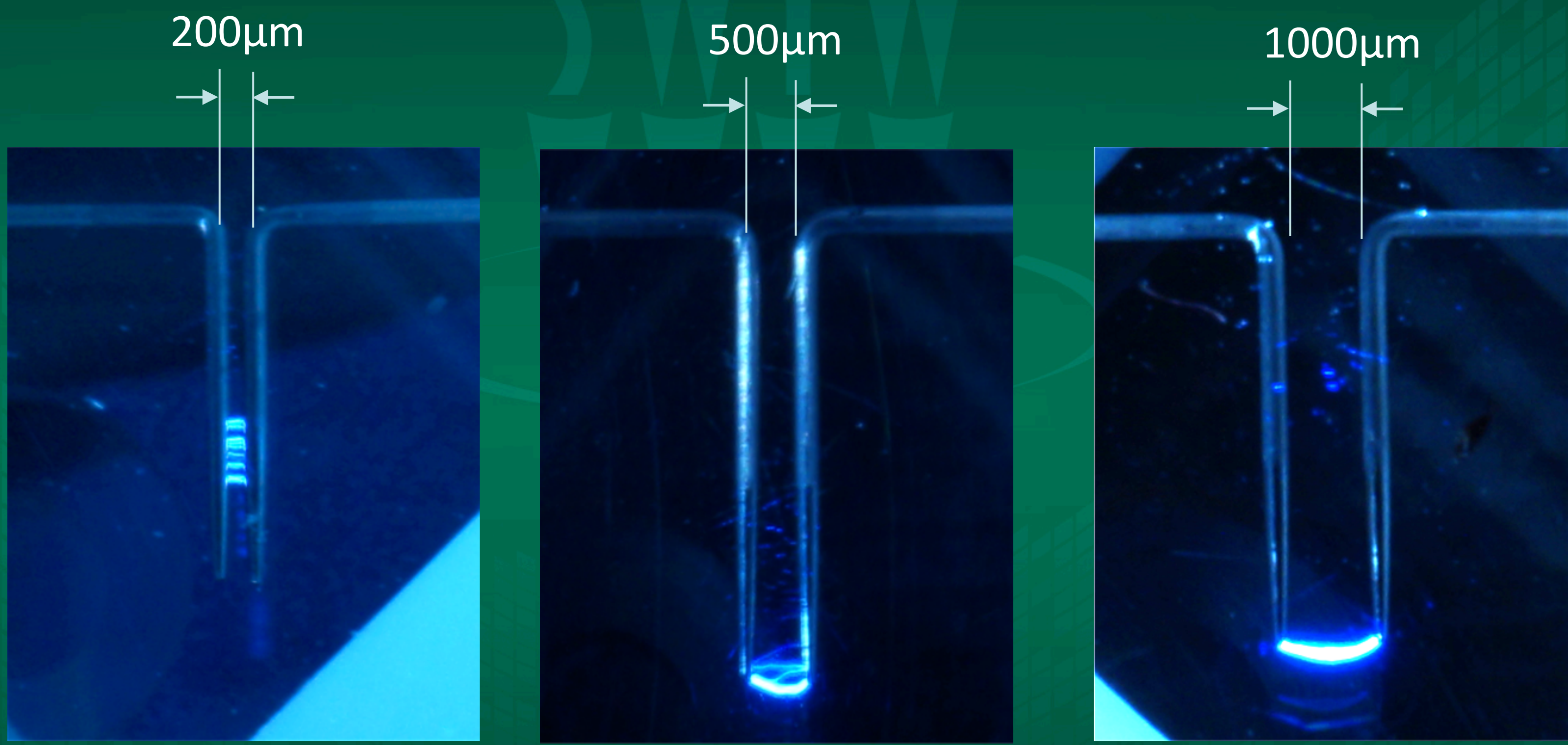
p = 4 bar absolute



increasing pressure ->
transition from streamer to spark

Flash-over high pressure

p = 7 bar absolute

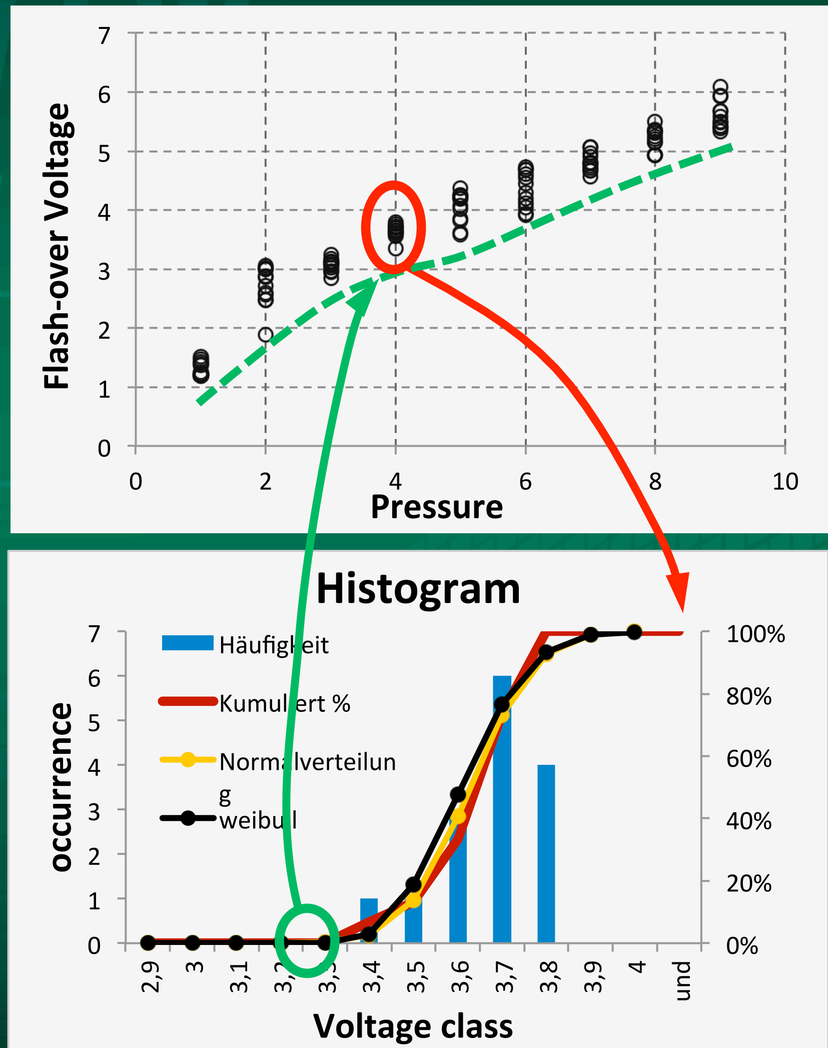


spark discharge only at probe tip:
intense visible light emission, audible

Experimental data processing

- **Statistical data analysis**
  - Histogram, cumulated
  - Weibull approximation
  - Amount of data limited, limited accuracy
- **Conclusion**
  - Withstand voltage*: flashover probability very low
  - Keep safety margin!

*limit for flashovers



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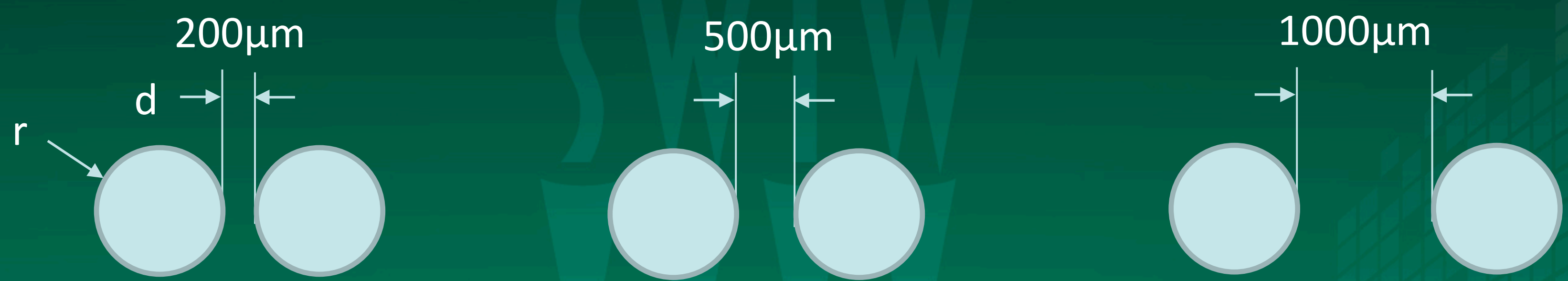
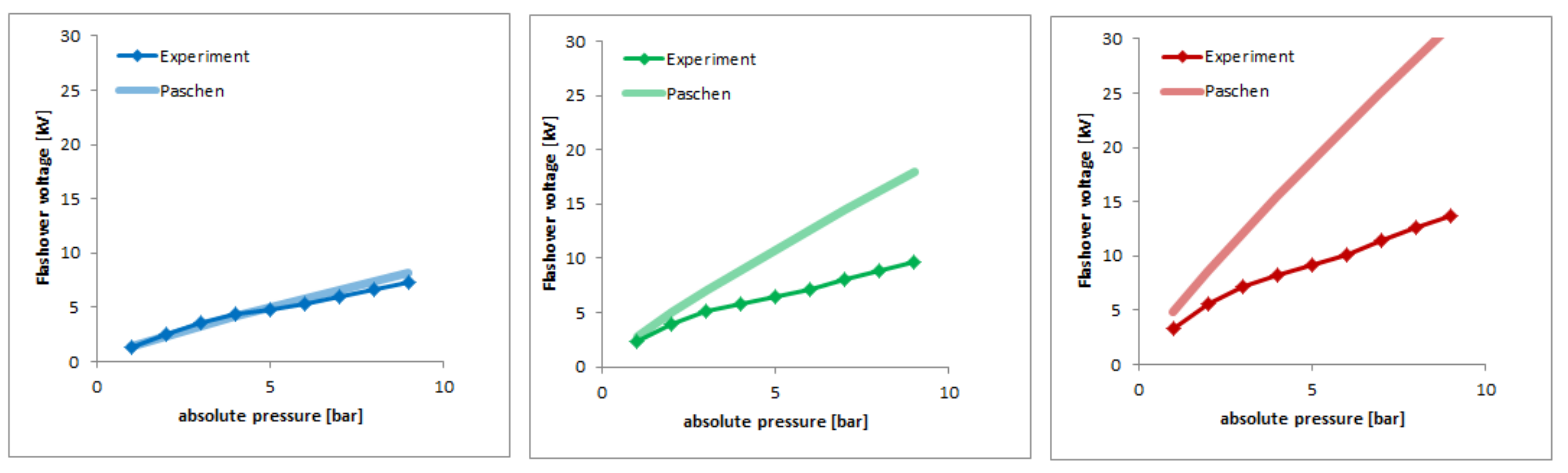
Flash-over voltage: experiment





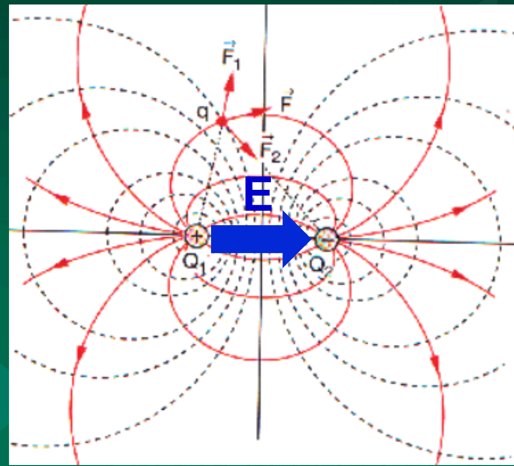
... good correlation with Paschen law only for homogenous electric field

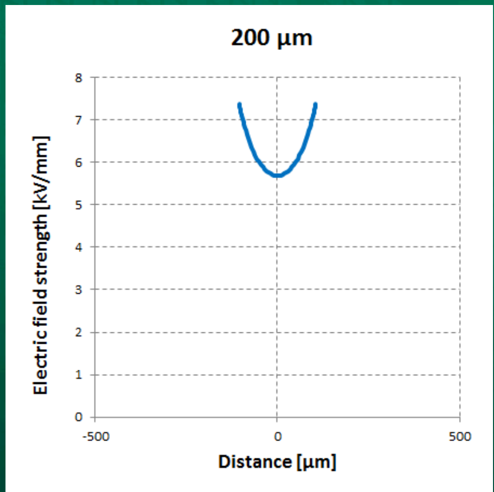
tungsten probes
10 mil diameter

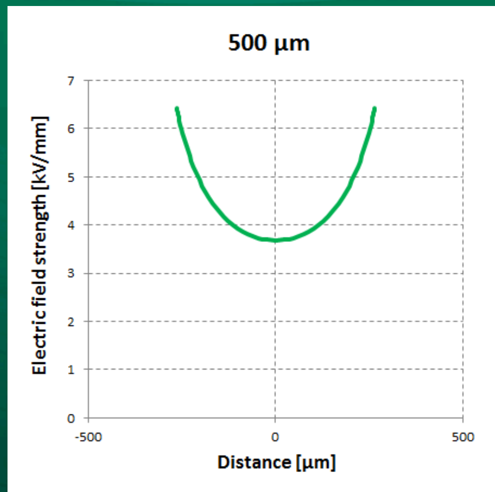
Electric Field - analytical

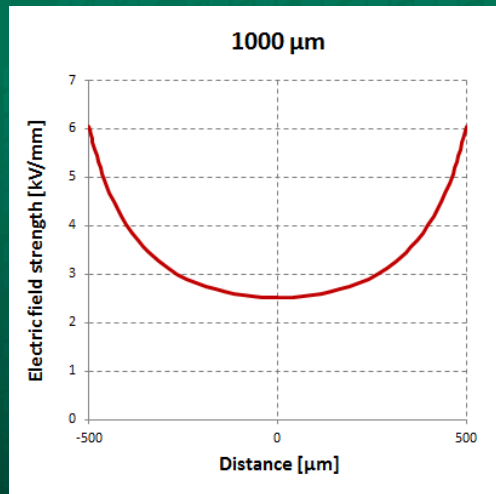
- **Parallel cylindrical conductors**
  - Analytical expression for field strength
  - cylinder radius r, center distance c
  - E= f (r,c,U)

$$E(x) = U \cdot \frac{1/\left(\frac{a}{2}-x\right) + 1/\left(\frac{a}{2}+x\right)}{\left(\frac{a}{2}+\frac{c}{2}-r\right)/\left(\frac{a}{2}+\frac{c}{2}+r\right)} \qquad a = 2\sqrt{\frac{c^2}{4}-r^2}$$



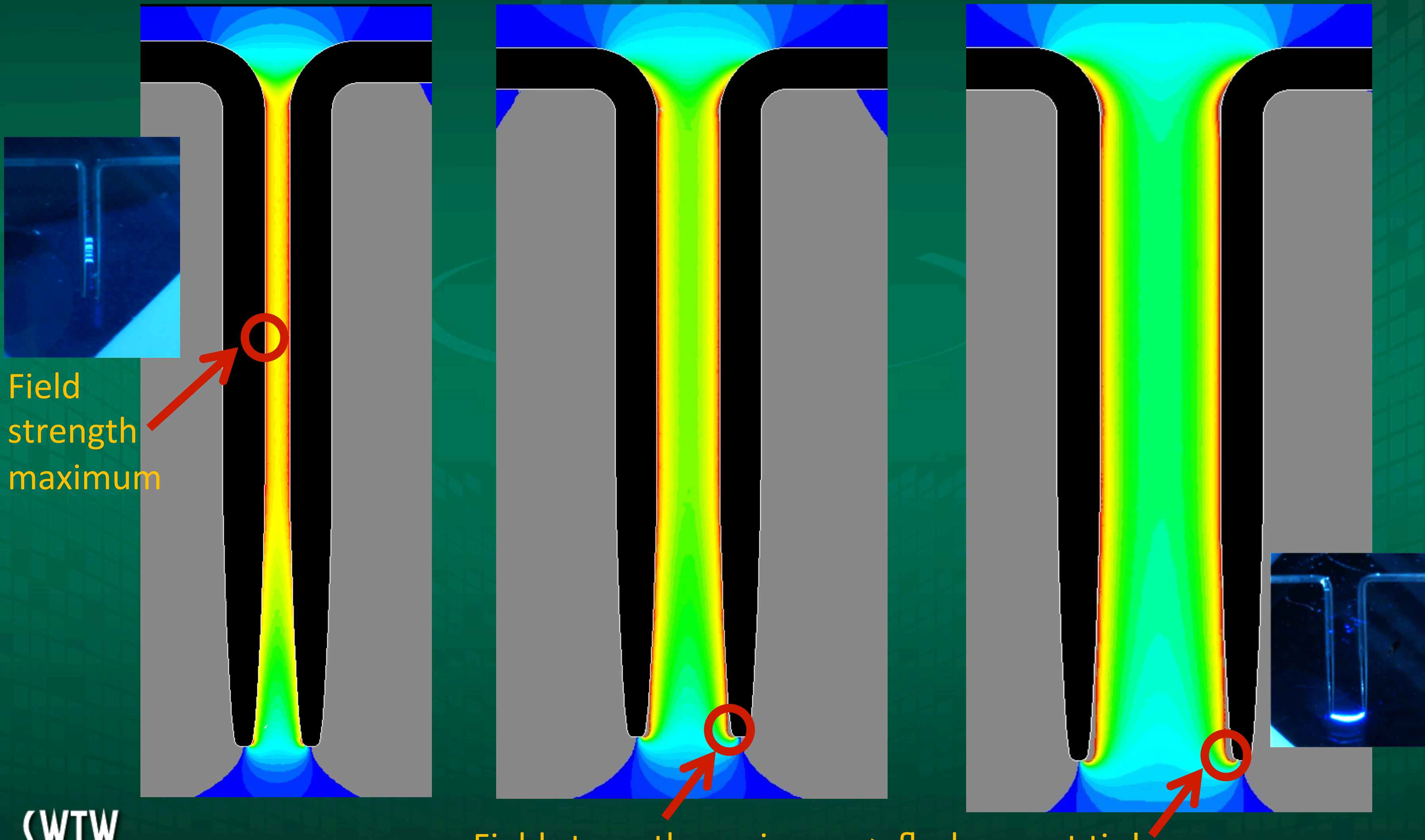






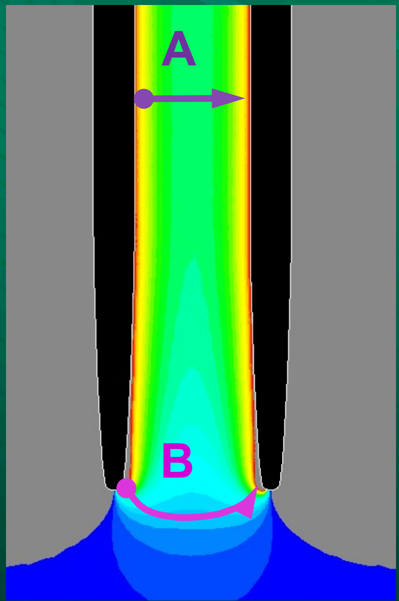
field strength calculated for experiment flashover voltage (at pressure = 1 bar)

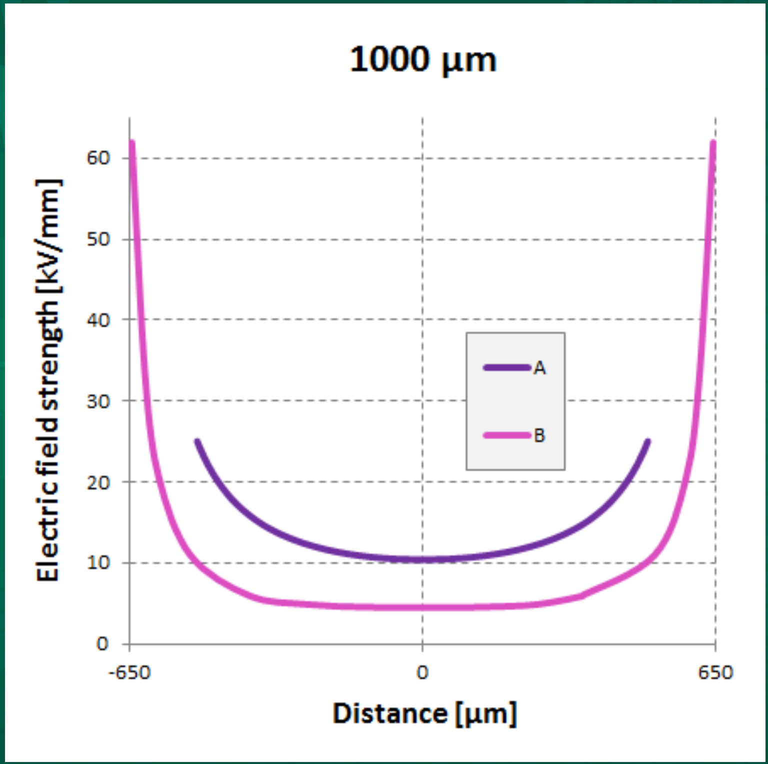
Electric field - FEM



Electric field inhomogeneity

- **Field concentration**
  - small radius at probe tip
  - local field strength maximum
  - despite lower field in middle
  - discharge along path B observed



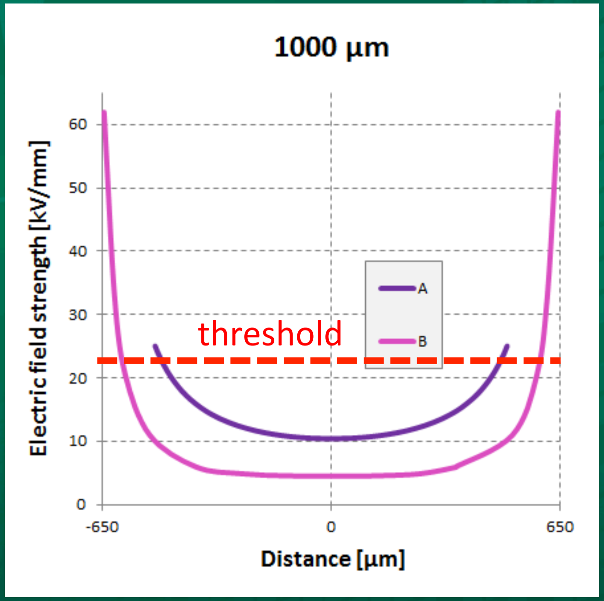


field strength calculated using flashover voltage (at pressure = 9 bar) from experiment

Streamer propagation

- **high field strength**
  - number of electrons grows exponentially along field line
  - if field stronger than threshold

- **low field strength**
  - if number of electrons $N > N_{krit}$
  - enough charge accumulated
  - charge enhances field
  - propagation continues



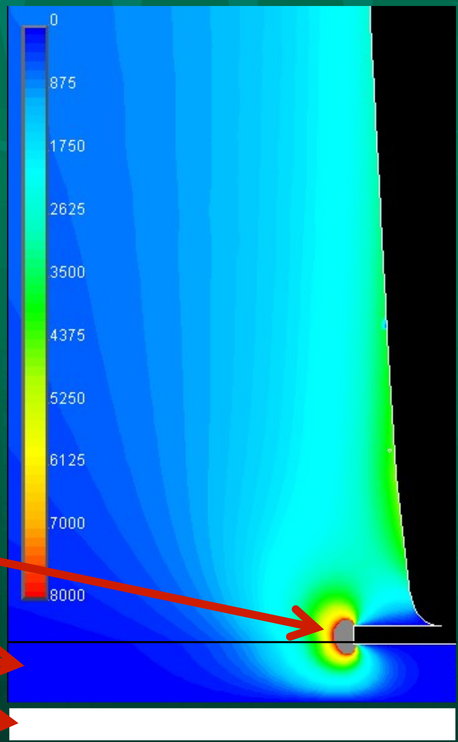
Wafer contacted: a different story...

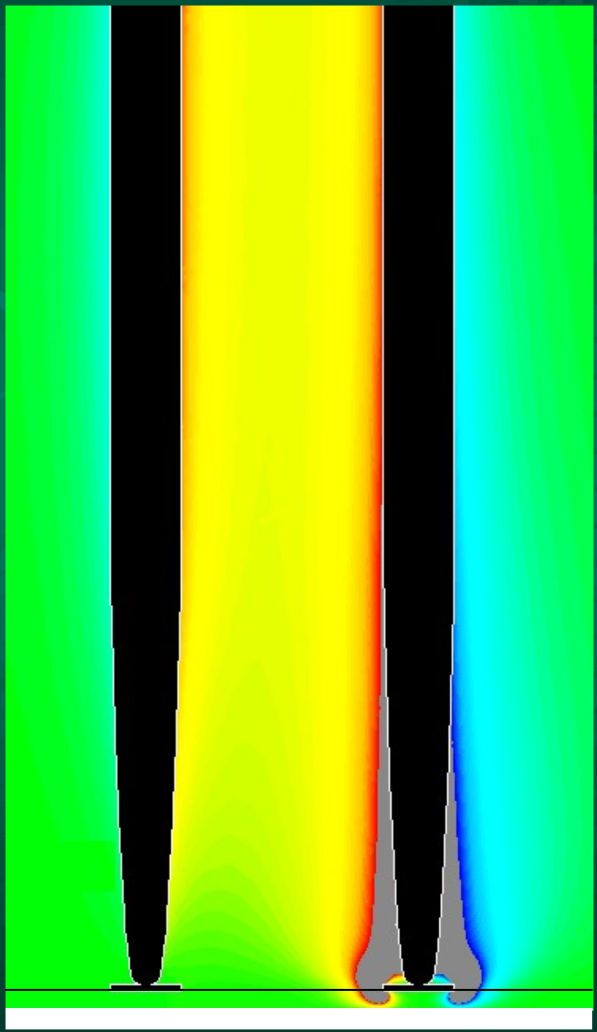
- **FEM**
  - Device geometry becomes dominant
- **Conclusion**
  - device sets the limit, not the probe card

Field strength many times higher than on uncontacted probes

Dielectric layer

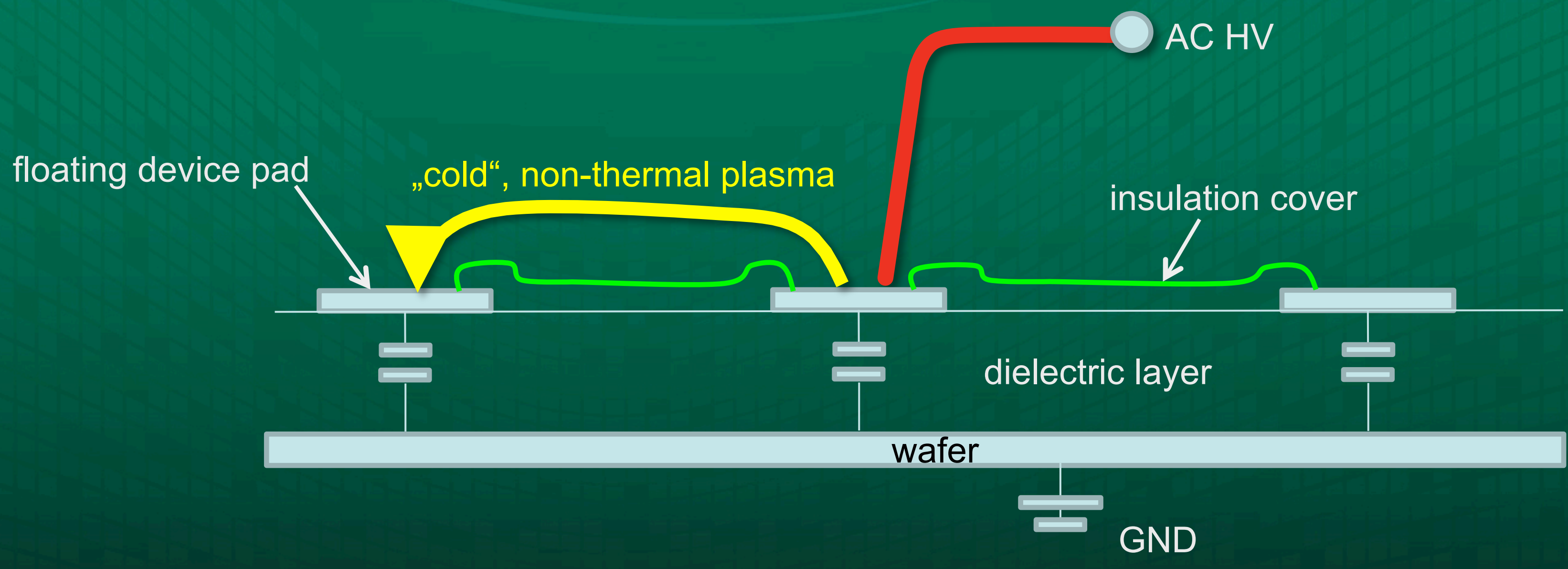
Wafer



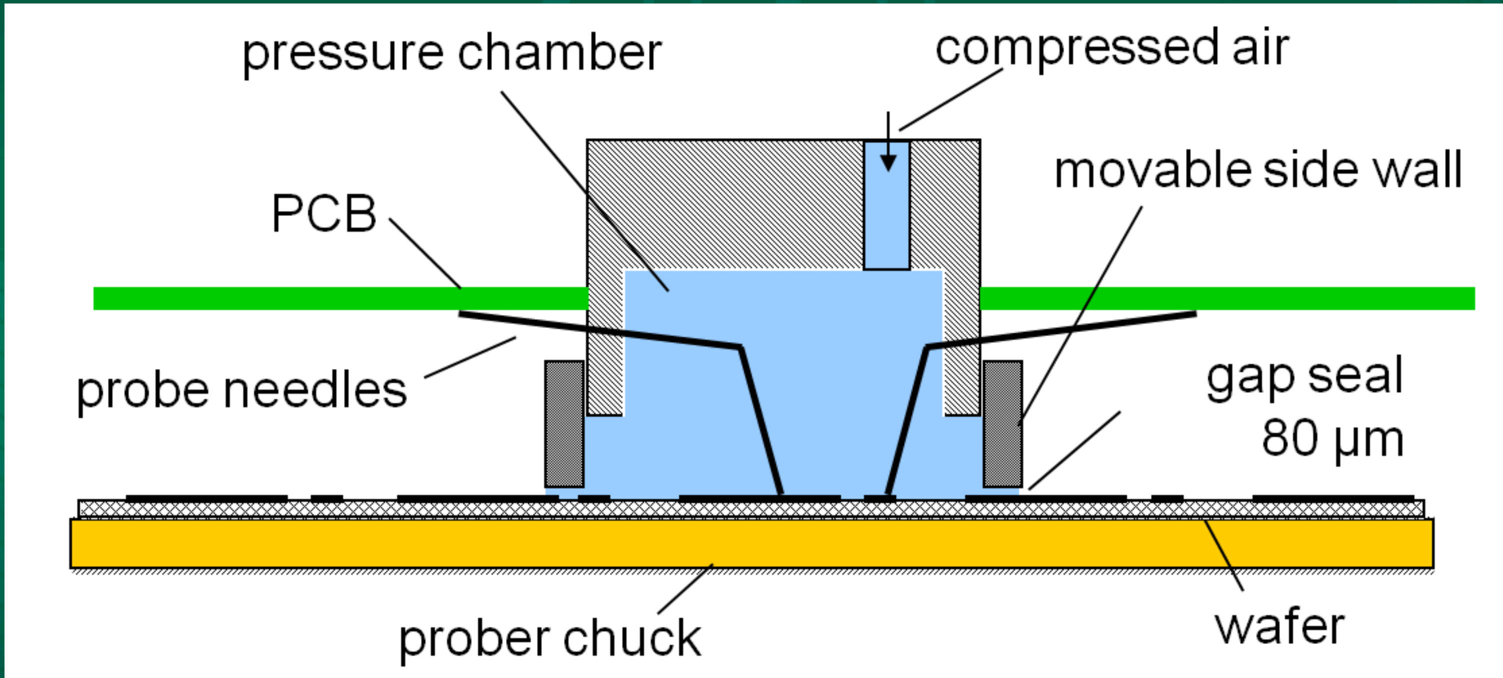


AC testing additional difficulties

- **Capacitively coupled discharge path to neighboring devices**
  - depending on specific capacity and geometry
  - Quasi-continuous partial discharge at AC frequency
  - "plasma etching" of wafer surface
    possible damage to e.g. polyimide insulation covers

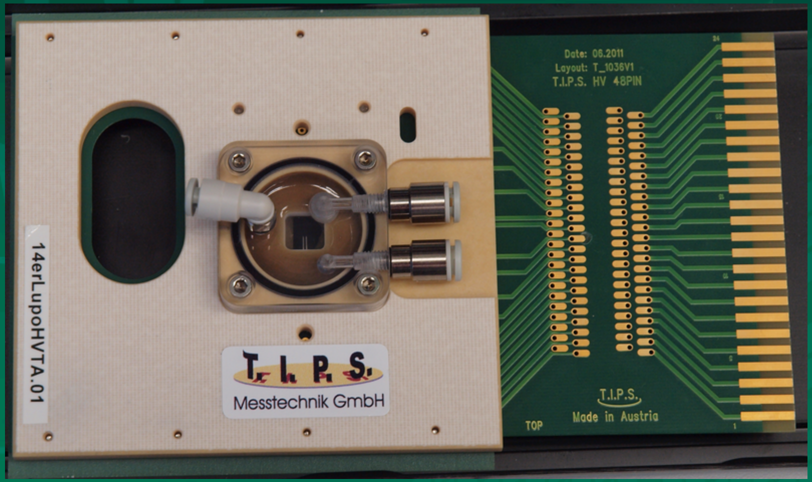


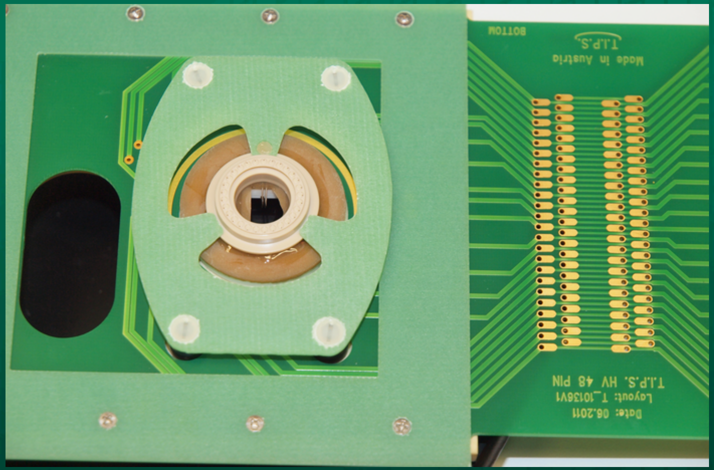
Luftpolster probe card



Luftpolster Probe card

- **Pressure chamber**
  - CDA supply up to 8 bar
  - Chamber pressure up to 6 bar
  - Lab tests up to 10 bar
- **Air bearing seal**
  - Seal ring hovering
  - No-contact operation
- **Features**
  - Optical window for alignment
  - can be operated on manual and automated probers
  - only one additional CDA line required





Summary

- **Test equipment:**
  - Simple design rules for HV probe card design confirmed
  - AC Flash-over strength was characterized
  - Measured behavior aligns well with theory
  - Probe card does not set the limits: flashovers occur between DUT terminals
  - DUT geometry becomes dominant – may require experimental verification
- **Additional AC test specific effects:**
  - Consider capacitive coupling to neighboring devices
  - Partial discharge may degrade device surface

Conclusion : You better know your field!

Acknowledgements

Named and unnamed contributing to this work:

- **our staff at TIPS Messtechnik**
- **customers that remain anonymous…**

- **References:**

  - A. Küchler, Hochspannungstechnik, VDI 2009
  - C. Louste et al, Sliding discharge in air, Journal of electrostatics 2005
  - S. Boenisch, ESD at small distances and voltages, TU Berlin 2004