LTEM electrostatic chucks, vacuum & humidity forces

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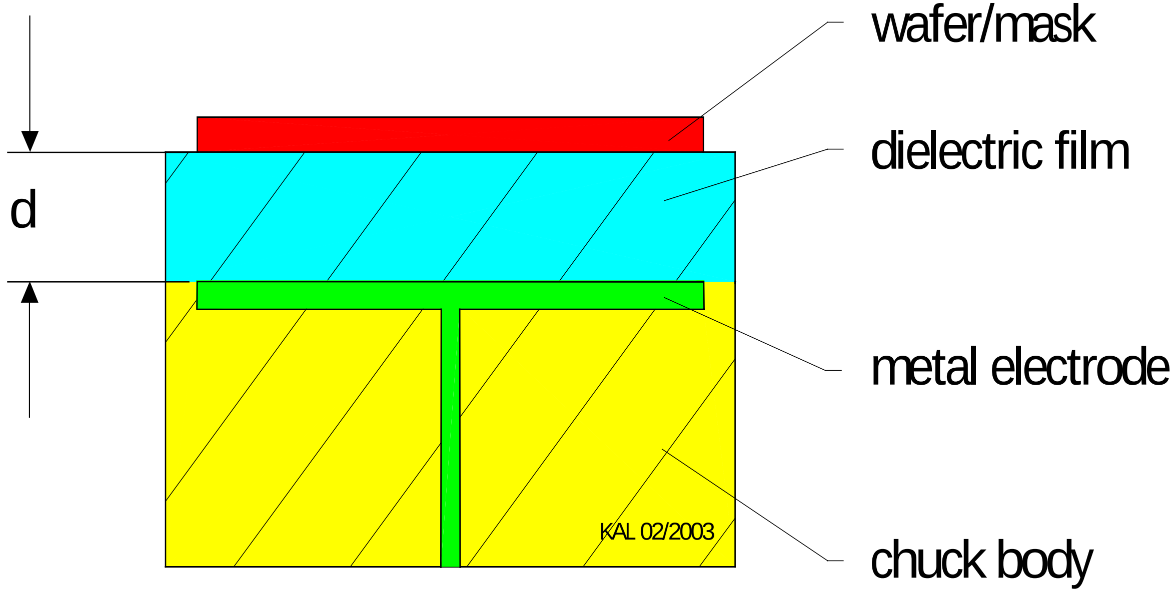
Outline

- Electrostatic chucking: basics
- EUV mask chuck requirements
- LTEM alternatives
- Vacuum & humidity force measurements
  with structured test chucks (ULE®, ZERODUR®)
- Conclusions

Electrostatic chuck (ESC) basics

$F = -\frac{1}{2}\,\varepsilon_0 \varepsilon_r^2 A\,(U/d)^2$
force @ zero air gap

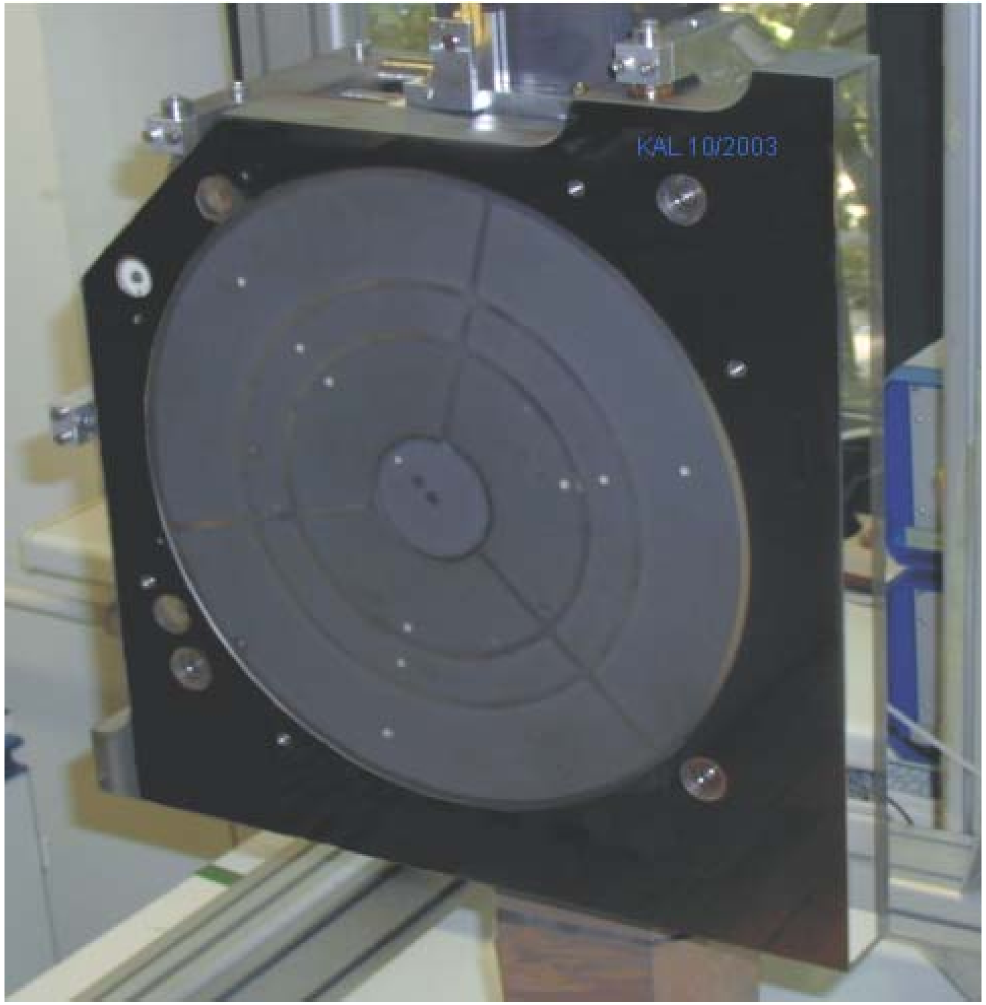
A: area
U: voltage
d: distance
ε_0: 8.8 10^{-12} As/Vm
ε_r: rel. dielectric constant



$F = -\frac{1}{2}\,\varepsilon_0\, A\, U^2/(\Sigma d_i/\varepsilon_i)^2$
more generally

$F/A \approx -15$ kPa @ U=3kV, d=200µm, ε_r=4
typical values for ULE

Example: 300mm ESC in wafer metrology unit

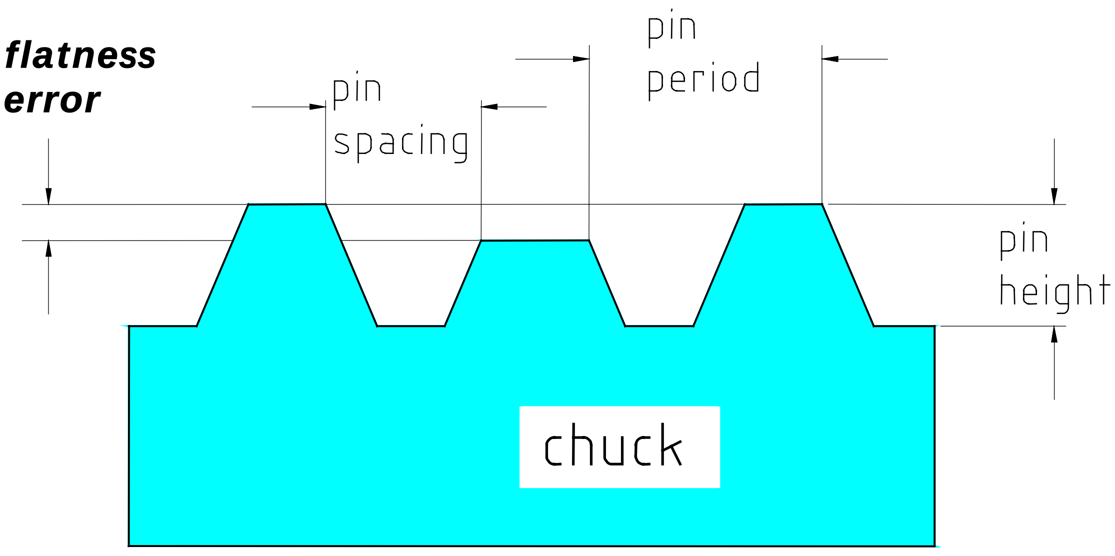


300 mm stage for
Ion Projection Lithography

- „zero expansion“ materials
- light-weight design
- interferometer mirrors:
  ultra high flatness
  & orthogonality
- high flatness chuck
- kinematic mount (6 DOF)

Courtesy LEICA Microsystems

EUV mask chuck requirements (SEMI#3419)



Clamping pressure <P> = 15 kPa ±10%
ΔP ≤ 3 kPa quality area

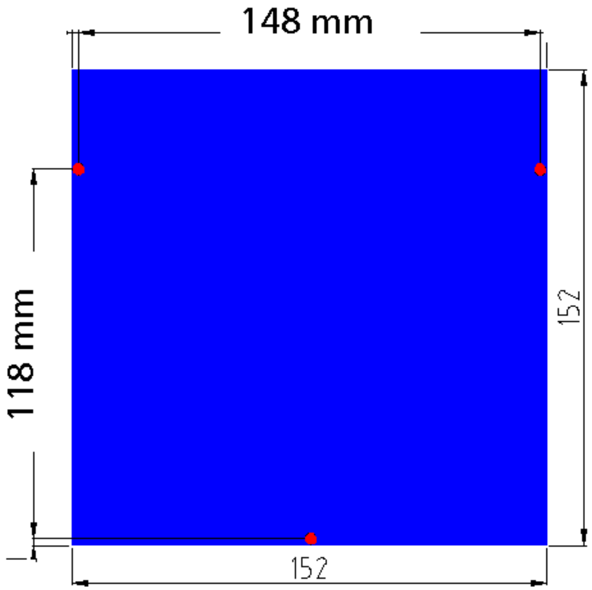
Bending stiffness ≥ 30 kNm

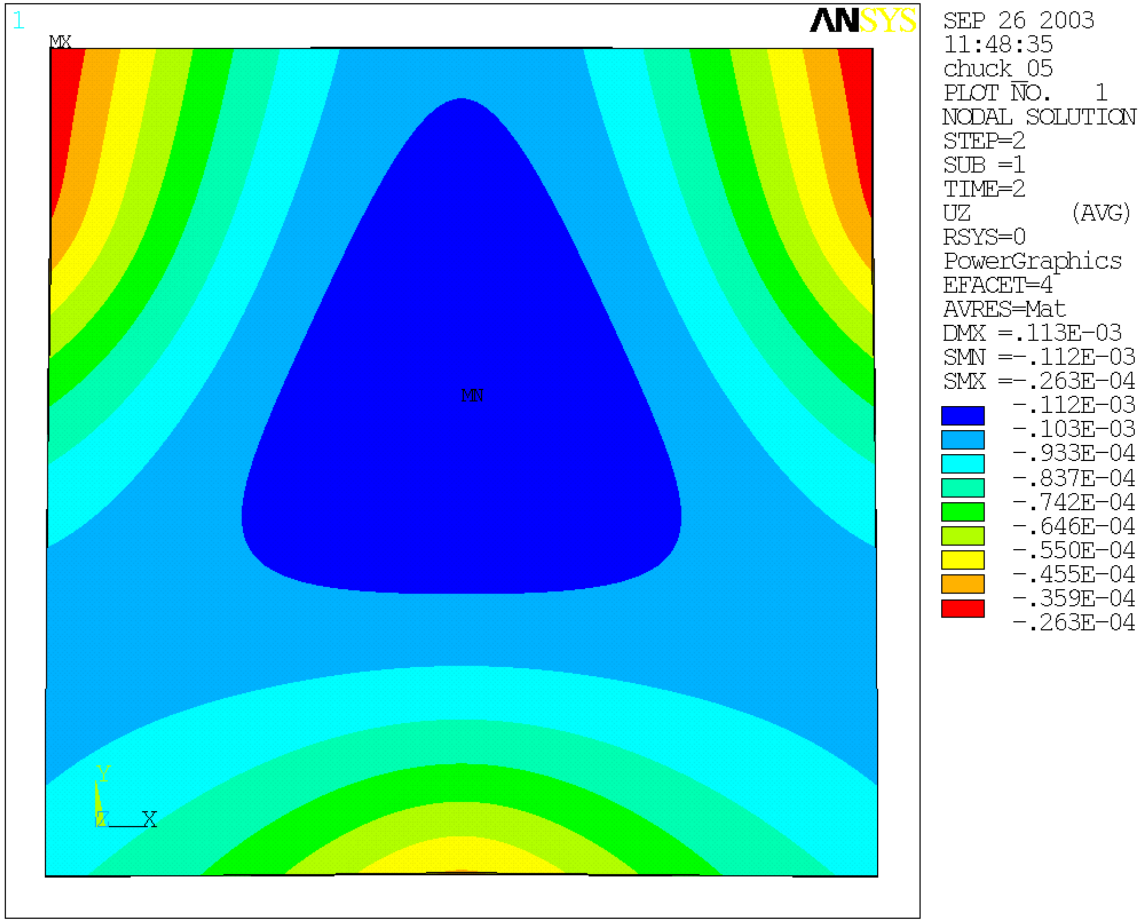
LowThermalExpansionMaterials

Flatness required (nm PV)	Field edge selected (mm)
2.5	10
3	12
4	15
5	20
7	25
12	40
24	75
40	150

printable field: 104by132mm

Gravity induced chuck bending





17.3 mm ULE® plate (↔30 kNm) on 3 point mask mount:

→ OPD≈ 86 nm (full area)

→ ***chuck mount is an issue***

LTEM Alternatives

		ULE® LTEM glass	***ZERODUR®*** LTEM glass-ceramics
Elastic modulus *	GPa	67.6	90.3
Poisson‘s ratio *		0.17	0.24
Density *	g/cm³	2.21	2.53
CTE (5...35 °C) (grade dependent)	1/K	1...2* 10^{-8}	2* 10^{-8}
Thermal Conductivity*	W/m/K	1.31	1.64
Dielectric const * (100Hz)		3.99	8.0
DC resistivity * ***200°C***	Ohm cm	≈ 10^{17} ≈ 10^{12}	≈ 10^{13} ≈ 10^{7}
Chucking behavior*		Coulomb	Johnsen-Rahbek

* room temperature

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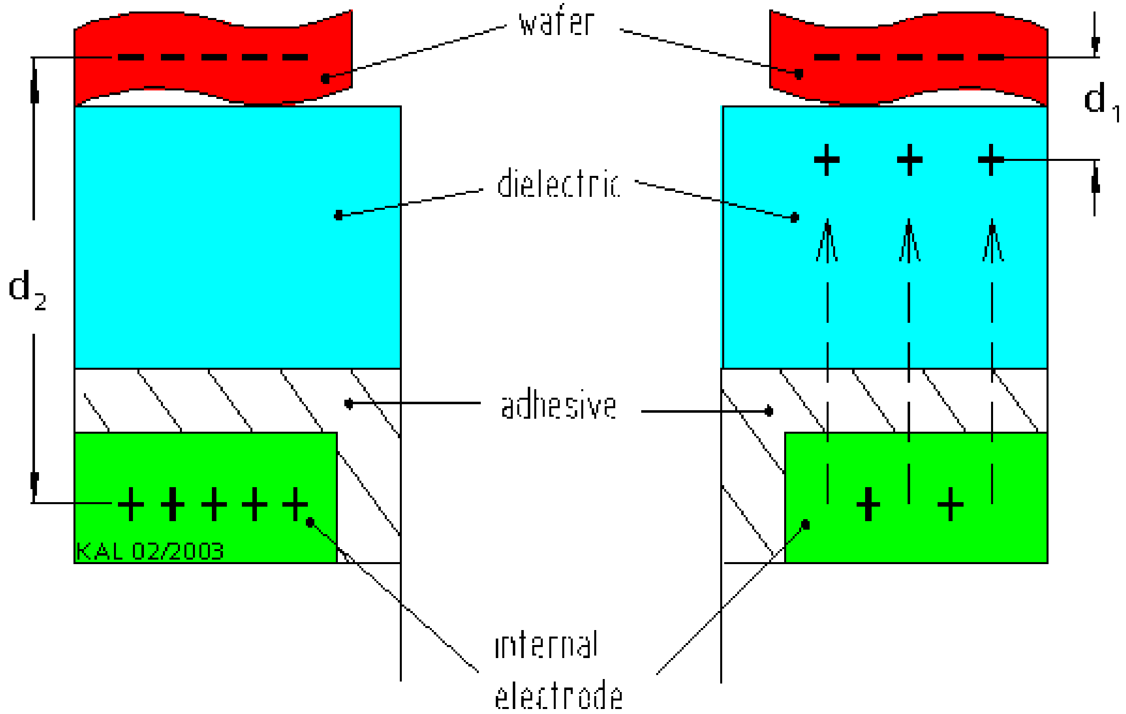
Different ESC dielectric regimes



Coulomb vs. Johnsen-Rahbek

Coulomb
„insulating“ dielectric
⇔ ULE®

Johnsen-Rahbek (JR)
„semiconducting“ dielectric
⇔ ZERODUR®

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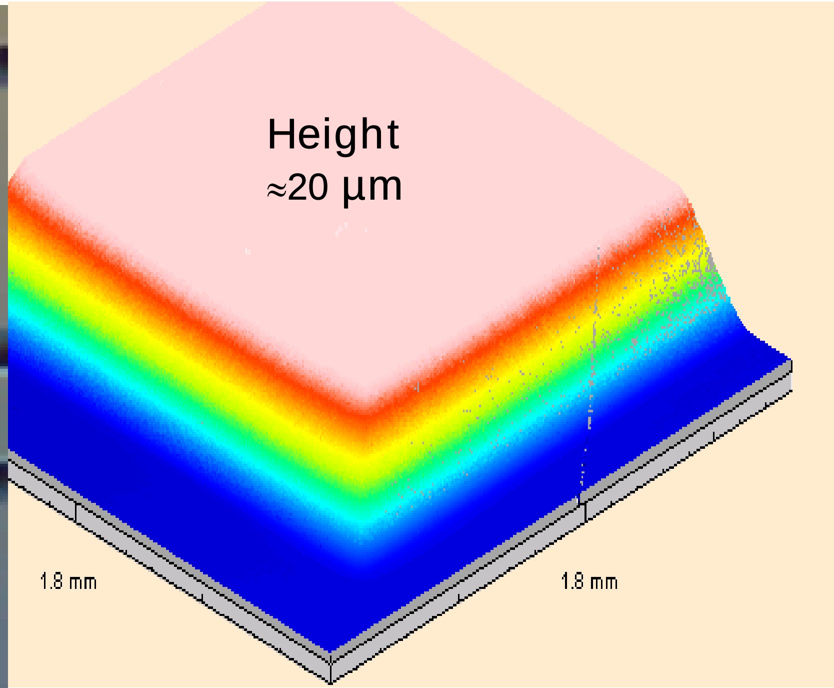
ULE® waffle chuck (Coulomb)

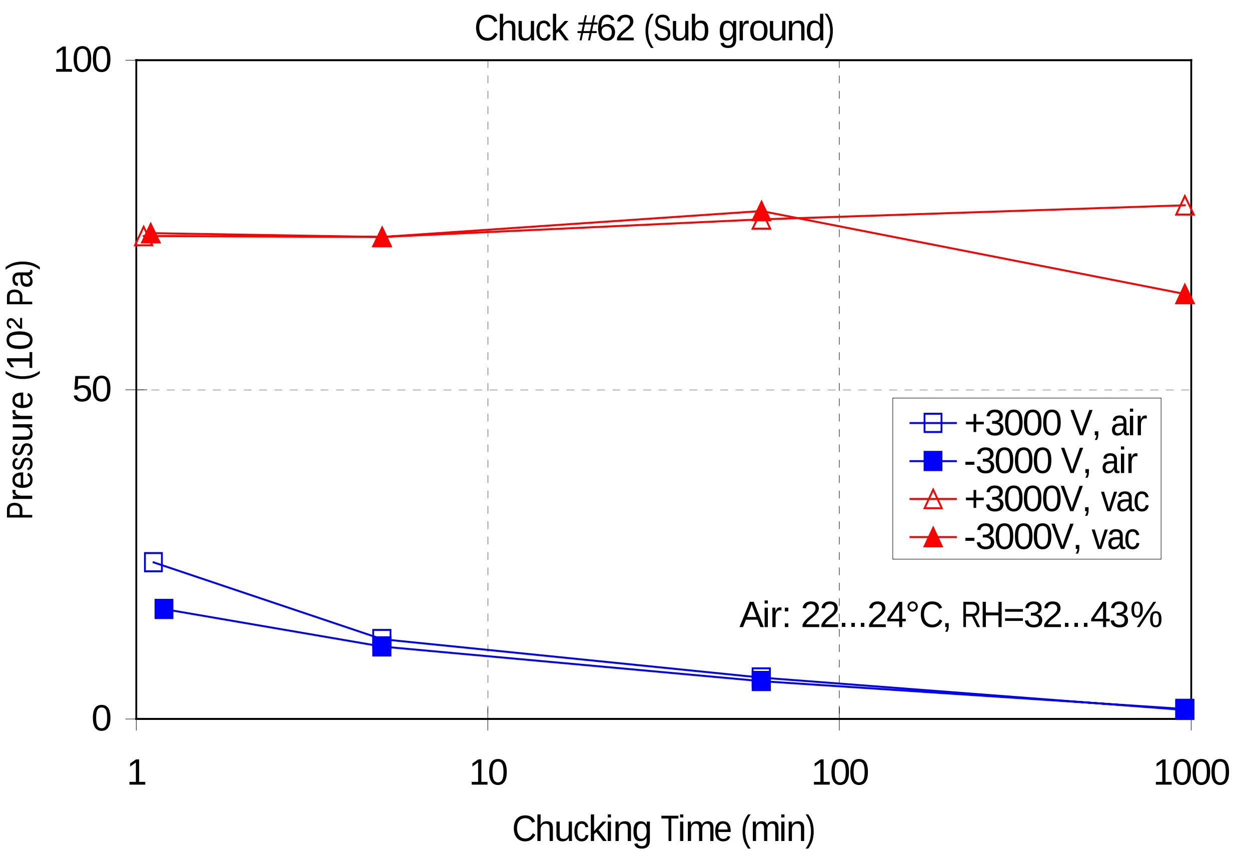


smooth slope without overhang

waffle ≈2mm*2mm (R_{rms}≈0.8µm)

pitch ≈3mm

ULE® „thick“ waffle chuck



Vacuum (10^{-5} mbar):

typical Coulomb behavior:

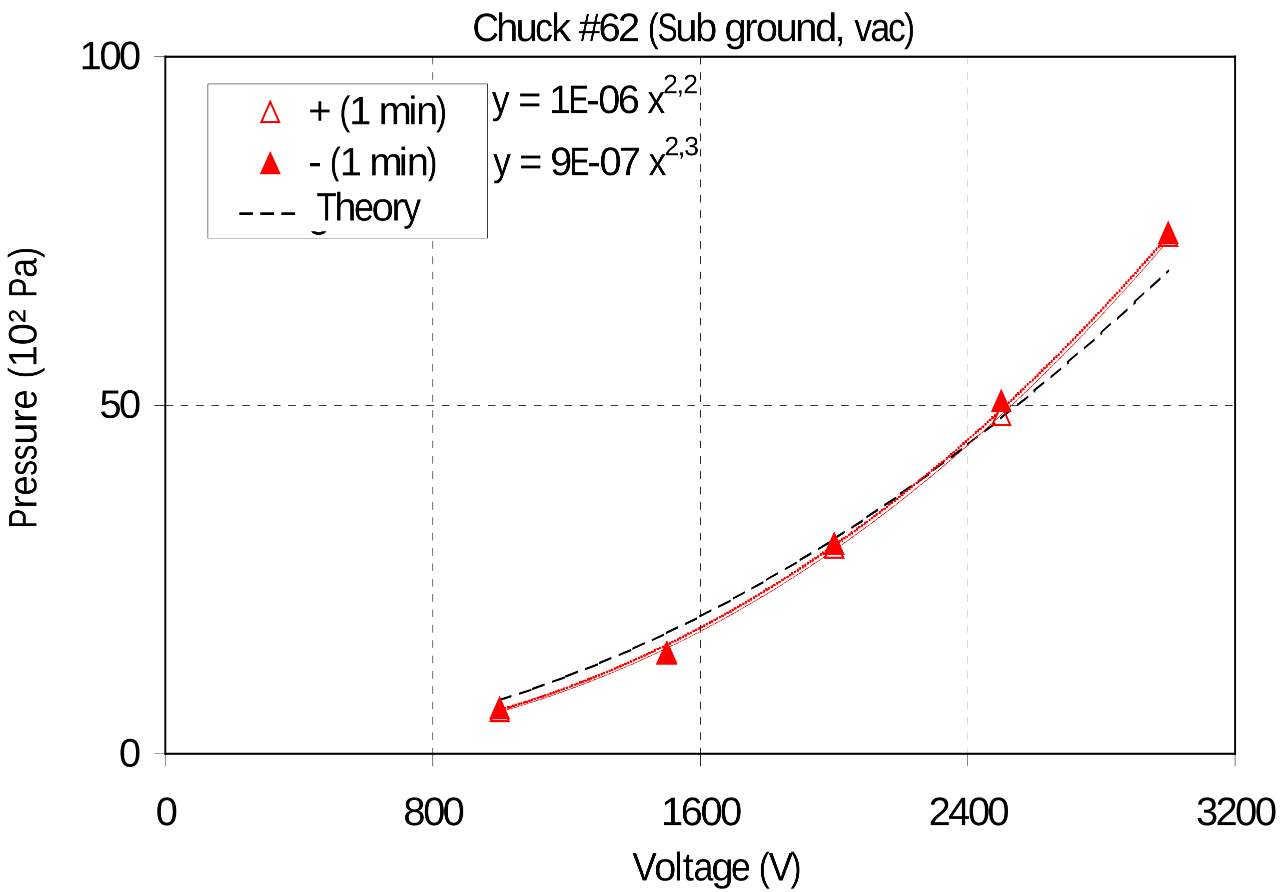
- modest forces
- „immediately“

Humidity:

- extremely reduced forces
- „from the start“

  (different to unstructured surfaces: see Kalkowski et al. Microelectron. Eng. 2002)

ULE® „thick“ waffle chuck

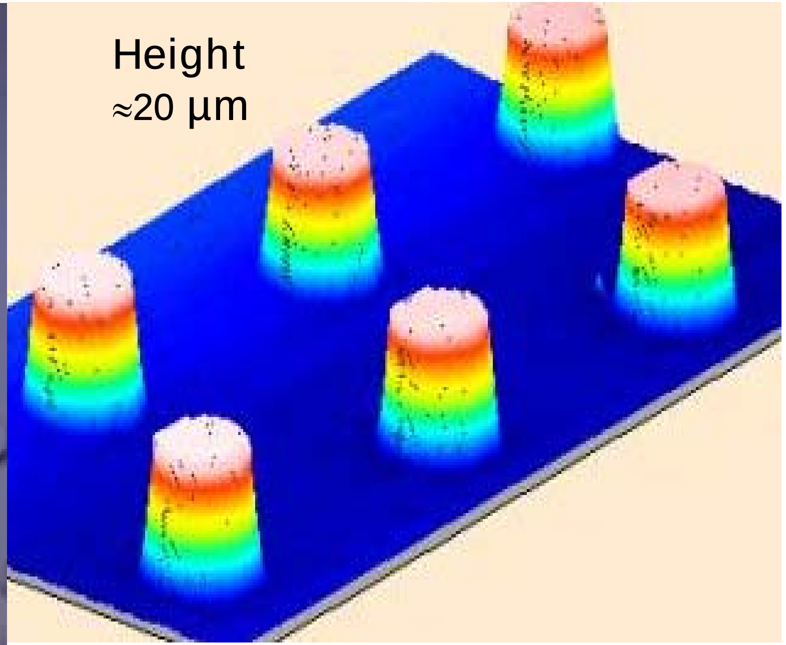


Test with simple Coulomb theory

(3-layers: adhesive, dielectric, air film $d_{total} \approx$ 250 µm thickness)

Coulomb theory describes ULE well (vacuum)

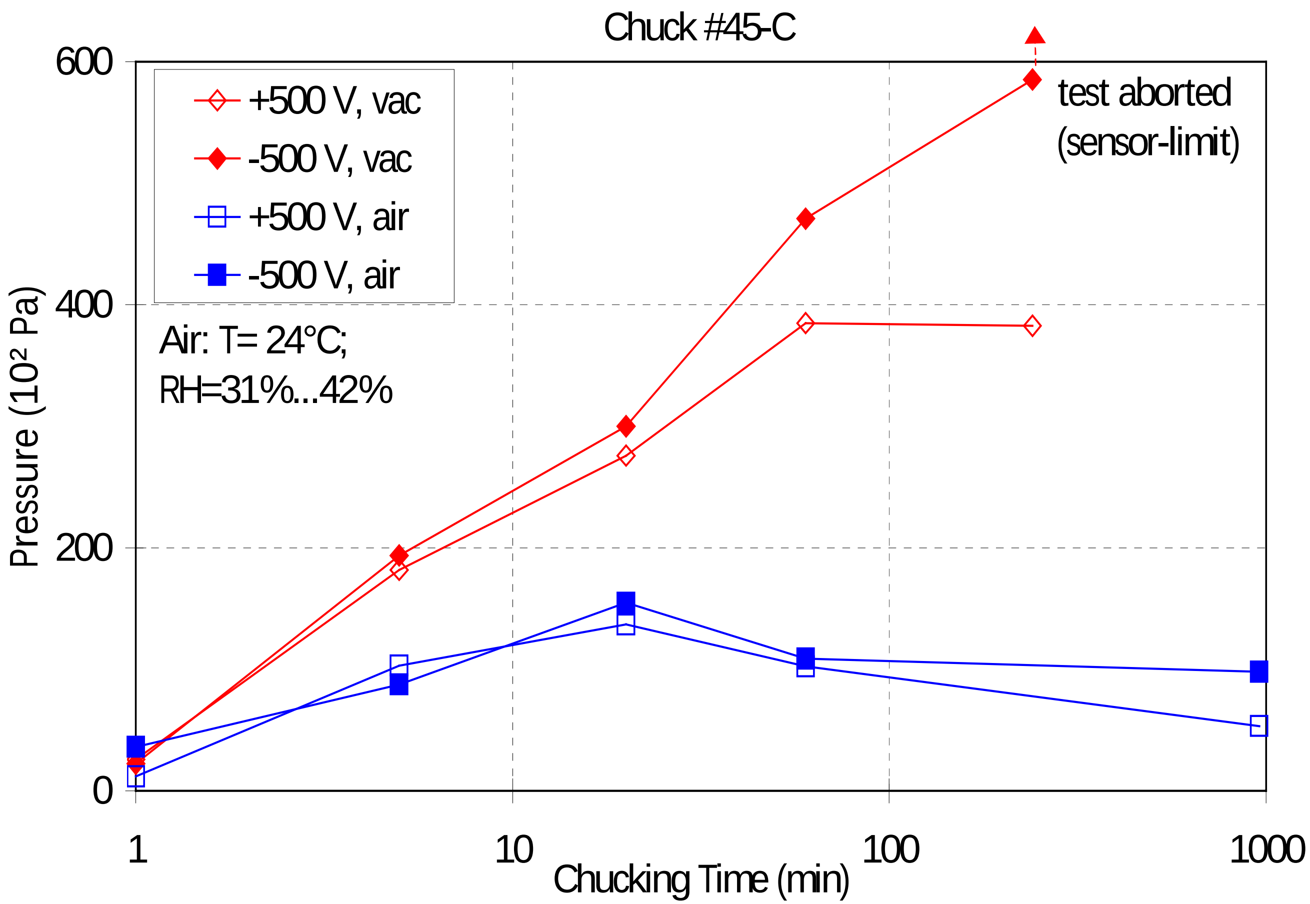
ZERODUR® pin chuck (Johnsen-Rahbek)



pin dia ≈1mm (R_{rms}≈0.02µm)

pitch ≈ 3mm

ZERODUR® „thick“ pin chuck



Vacuum (10^{-5} mbar):

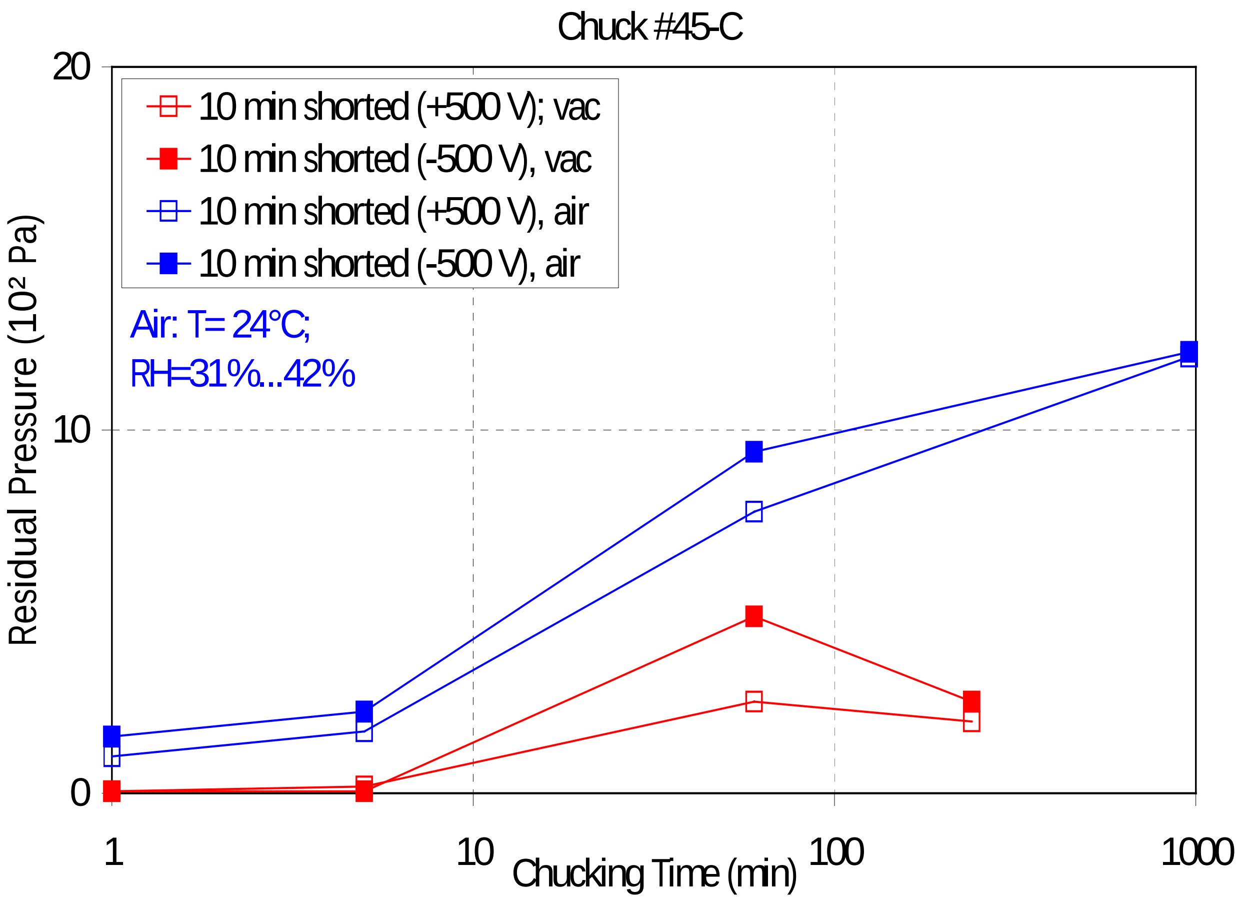
typical Johnsen-Rahbek behavior:

- huge forces
- „delayed“ onset

Humidity:

- forces reduced, but high compared to ULE
- initially „scaling“ with vacuum values, then declining

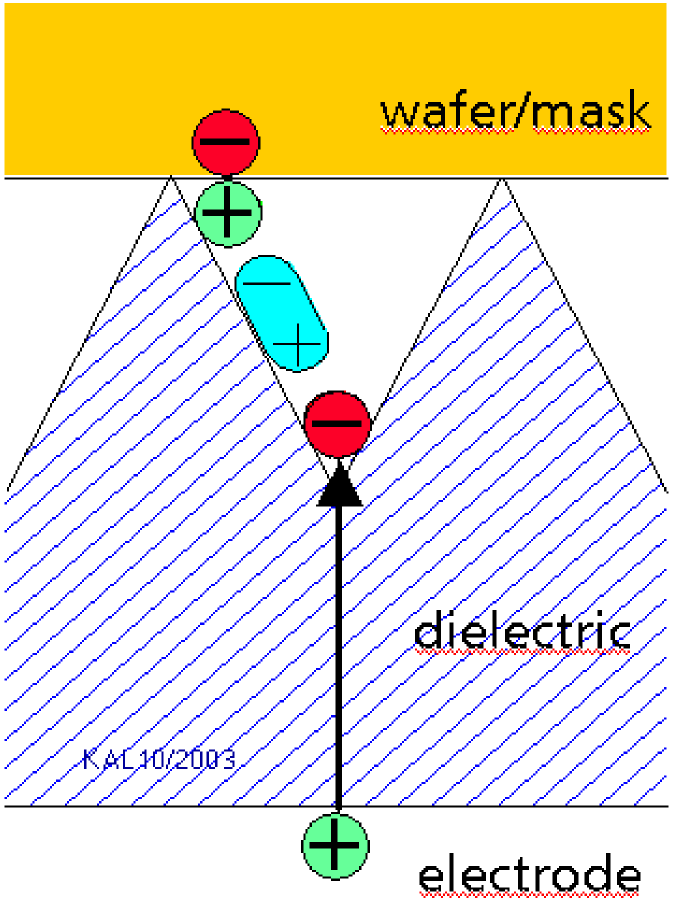
ZERODUR® „thick“ pin chuck



Residual forces
(@ voltage off):

- residual forces develop in vacuum, „scale“ initially with JR- forces
- residual forces “from the beginning” at humidity

Humidity model proposed



1) Paschen breakdown &
   field induced dissociation
   ($H_2O \rightarrow H^+ + OH^-$) at HV
   on chuck surface

   $\rightarrow$ wafer/mask shielding
   from electric field
   originating at chuck electrode
   $\leftrightarrow$ force reduction

2) charge trapping in surfaces
   $\rightarrow$ residual forces

Conclusions

Different LTEMs were used for electrostatic chuck manufacture & evaluation in vacuum and humidity:

1. Chucks with well defined surface structures (waffles, pins) were manufactured by lithographic techniques for ULE and ZERODUR.

2. Vacuum:
   Simple Coulomb theory describes ULE „waffle“ chuck well;
   Huge Johnsen-Rahbek forces are observed for a ZERODUR „pin“ chuck.

3. Humidity:
   At ambient humidity, electrostatic forces decrease strongly and residual forces develop.
   This is attributed (within a qualitative model) to E-field shielding and charge trapping at the chuck surface.

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