



UNIVERSITÄT
DES
SAARLANDES

Lehrstuhl für Funktionswerkstoffe



**Material Engineering Center
Saarland (MECS)**

Steinbeis-Forschungszentrum

Maßgeschneiderte Oberflächen durch Laserstrukturierung – von verschleißarm bis antimikrobiell

Prof. Dr.-Ing. Frank Mücklich

*Lasertechnologie – Einsatz in der Materialverarbeitung,
Materials Valley - Hanau 2015*

Lehrstuhl für Funktionswerkstoffe
Uni des Saarlandes
Grundlagen

Material Engineering Center
Saarland
Steinbeis Forschungszentrum
Industriekooperationen



Internationalität
Flavio Soldera



Elektr.Kontakte
Kim Trinh



Kupfer
Michael Hans



Laborleiter
Christoph Pauly



Aluminium
Michael Engstler



Oberflächen
Carsten Gachot

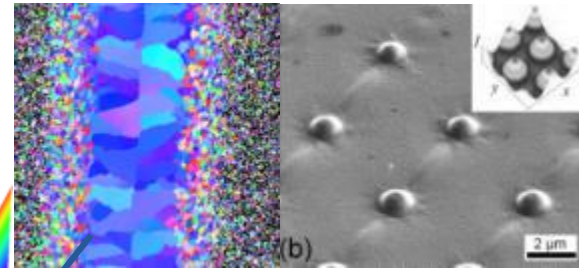
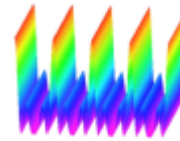
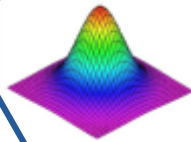
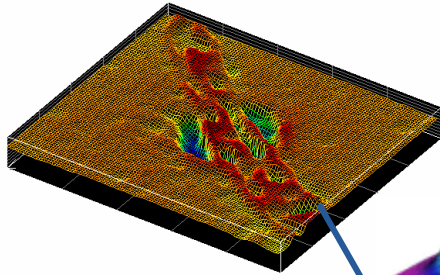


Stahl
Dominik Britz



Tomographie
Jeni Barrirero

New Materials



New Surfaces



- surface stability
- electro erosion
- **contact materials**
- metallic materials
- energetic Materials
- CNT based materials

- architected surfaces
- topography, phases, grains
- **Laser Interference Metallurgy**
- **micro / nano tribology**
- **anti microbial surfaces**
- new functionalities



Andreas Rosenkranz

Tribologie an Oberflächen mit maßgeschneidertem topographischen Design
Dissertation (summa cum laude) 2015



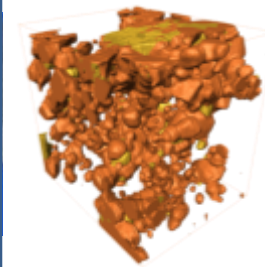
Michael Hans

Materialeinflüsse bei der Abtötung von Bakterien durch metallisches Kupfer
Dissertation (eingereicht) 2015



Kim Trinh

Laserinterferenzstrukturierung elektrischer Steckverbinder für die Automobilindustrie
Dissertation (eingereicht) 2015



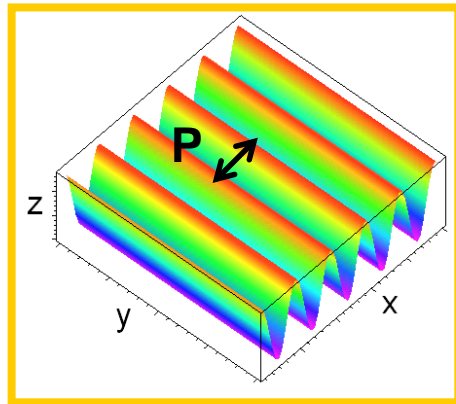
structures

scale

3D analysis

Example: **two beams** interference

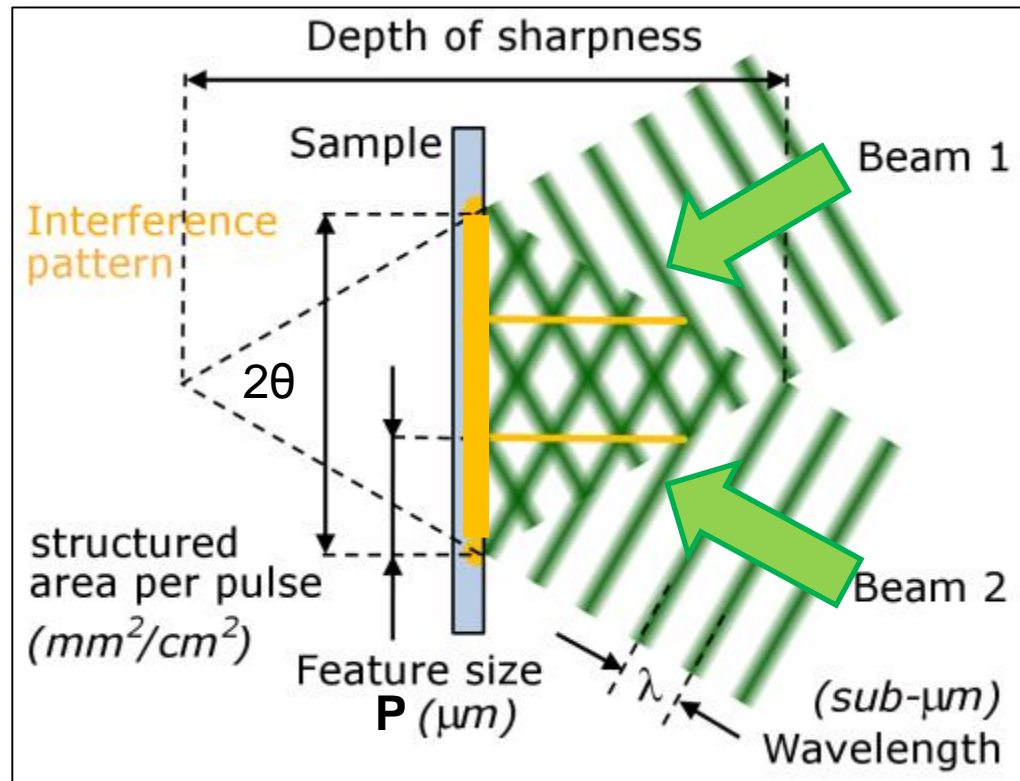
high power pulsed, nanosecond laser
(10 ns, 200 MW, 10 Hz, λ : 266-1064 nm)



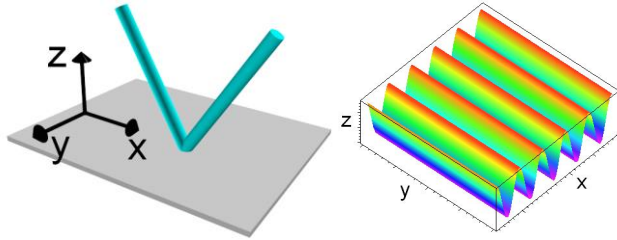
spatial intensity distribution

simplified equation:

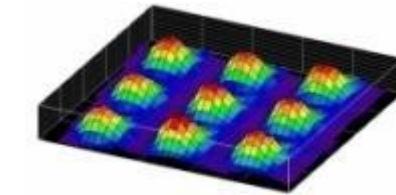
$$P = \lambda / (2 \sin(\theta))$$



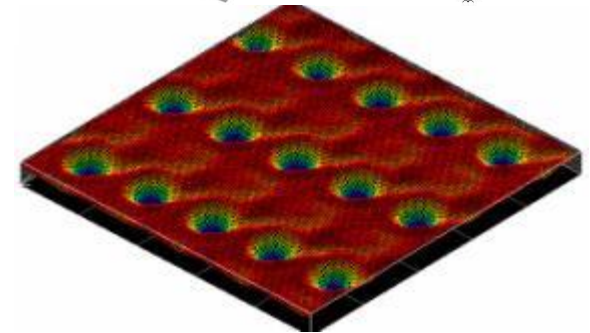
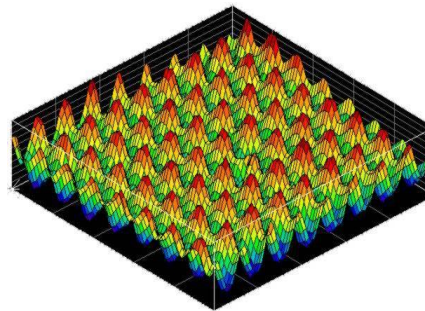
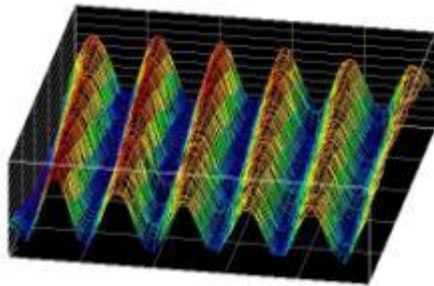
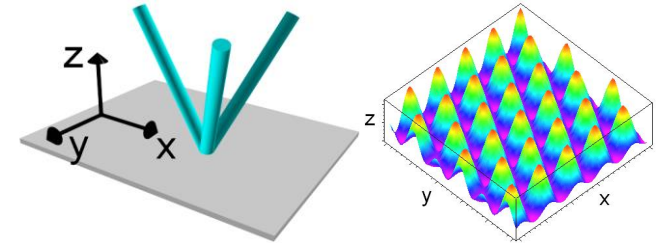
intensity line arrays



intensity lattices



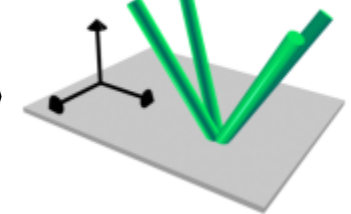
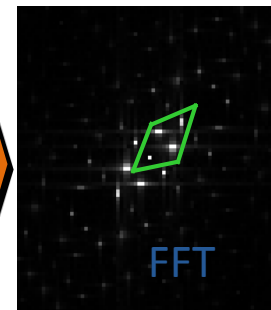
intensity dot arrays

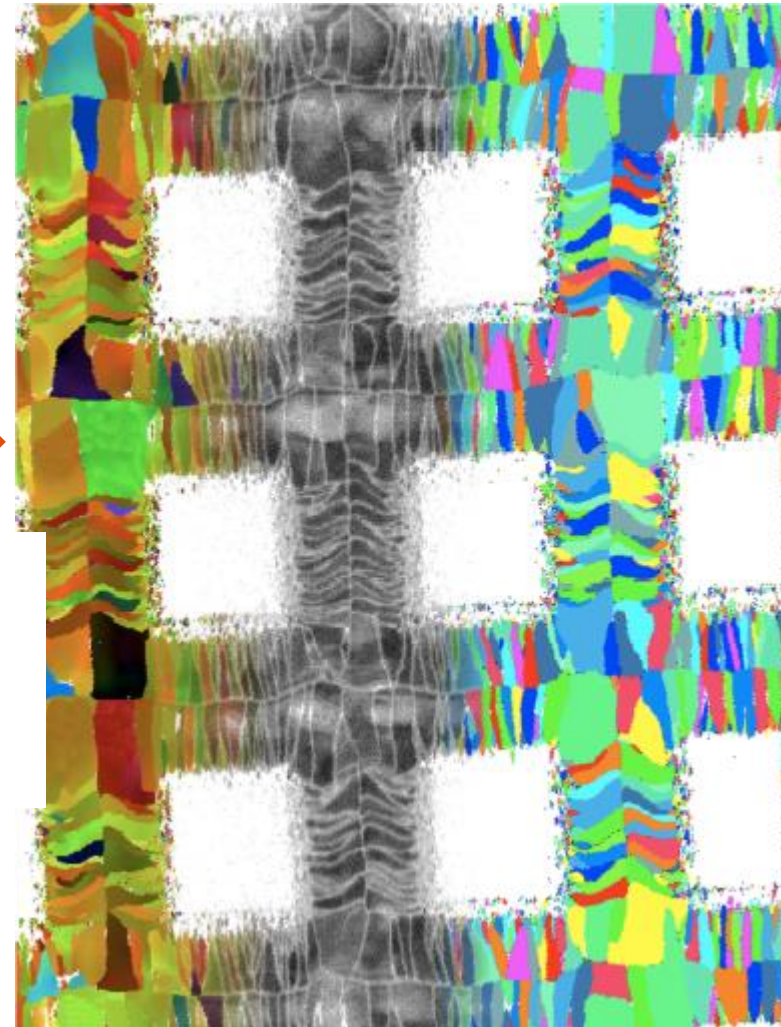
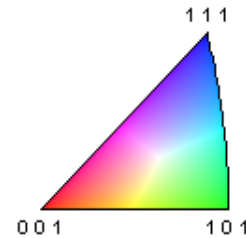
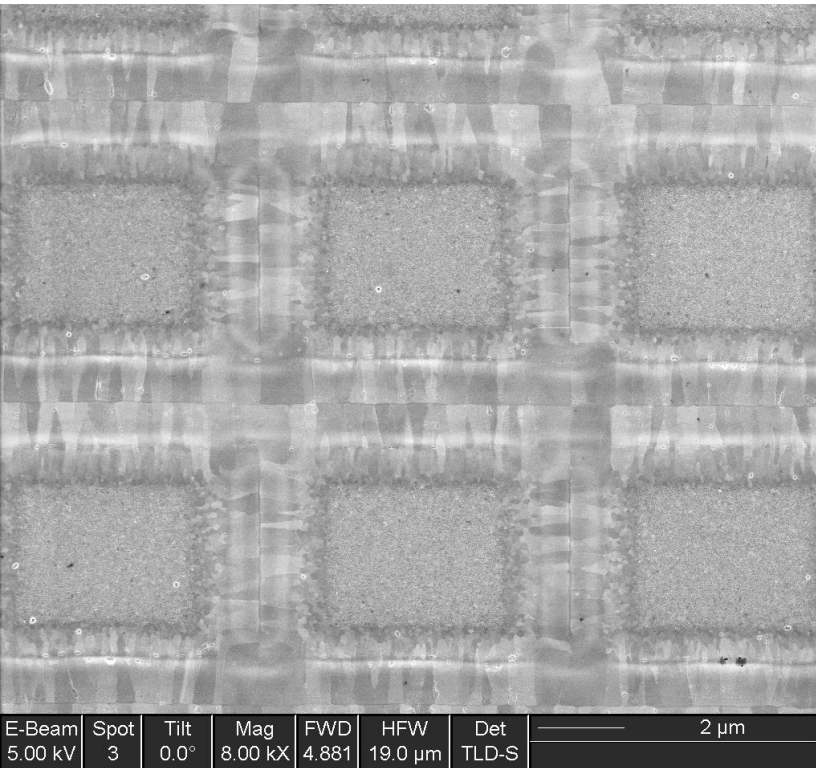


general equation:

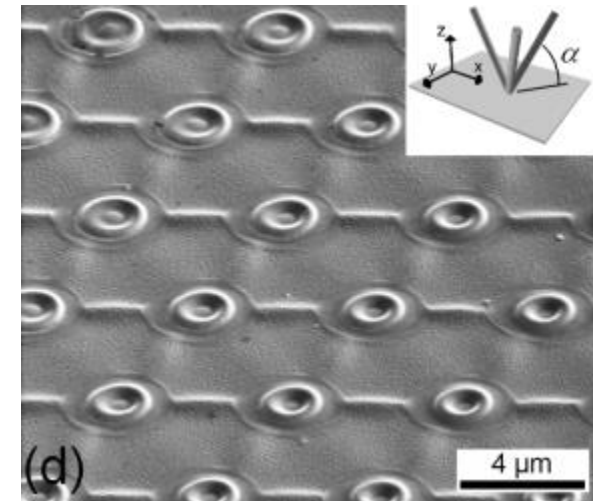
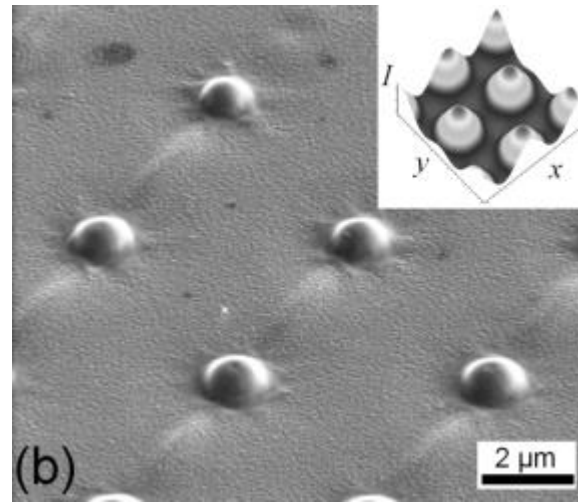
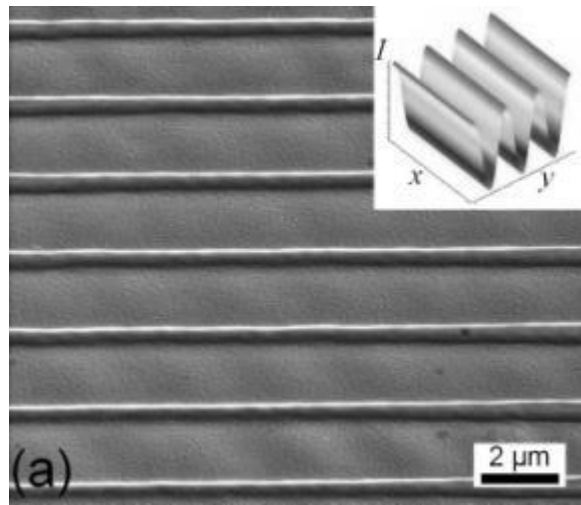
$$I(x) = I_0 \left| \sum_j c_j e^{-i\omega t} e^{ik_j x} \right|^2$$

number of beams j

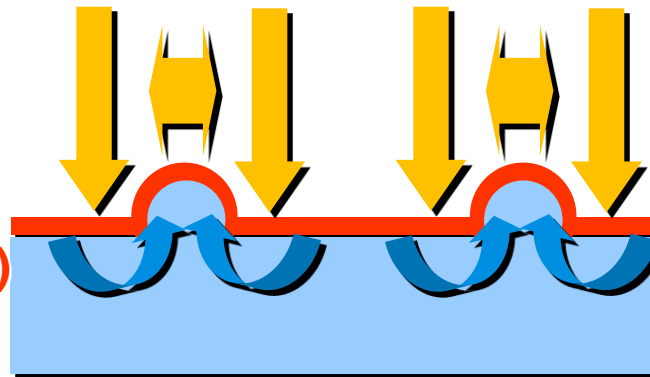




R. Catrin, F. Muecklich
Acta Mat. 2011



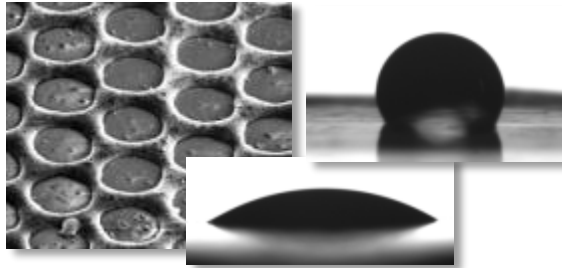
high speed
deformation (ns)



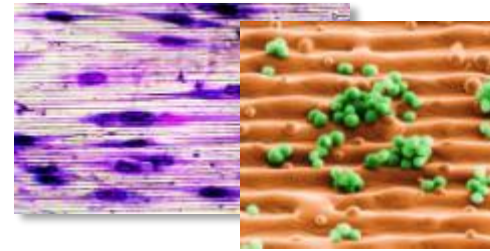
[A. Lasagni, C. Holzapfel and F. Mücklich, Adv. Eng. Mat. , 7 (2005) 492-507.]

Vielfalt maßgeschneiderter Funktionalisierung → durch *Laser Interferenz Strukturierung*

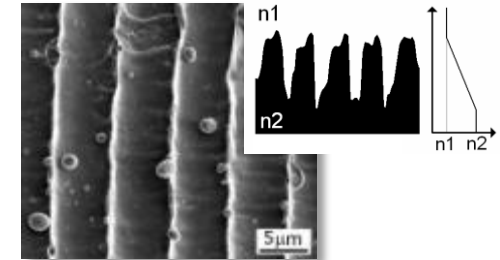
Wetting



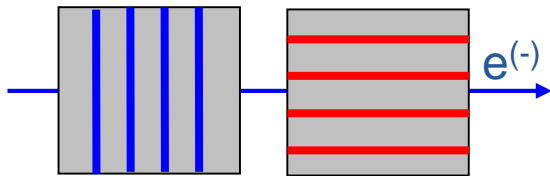
Bio-Functionalization



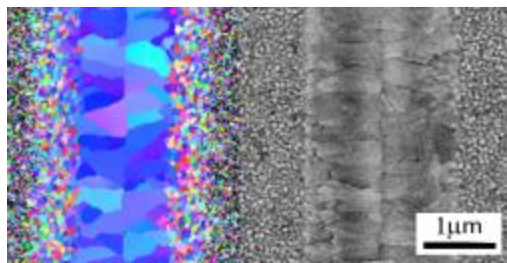
optical Properties



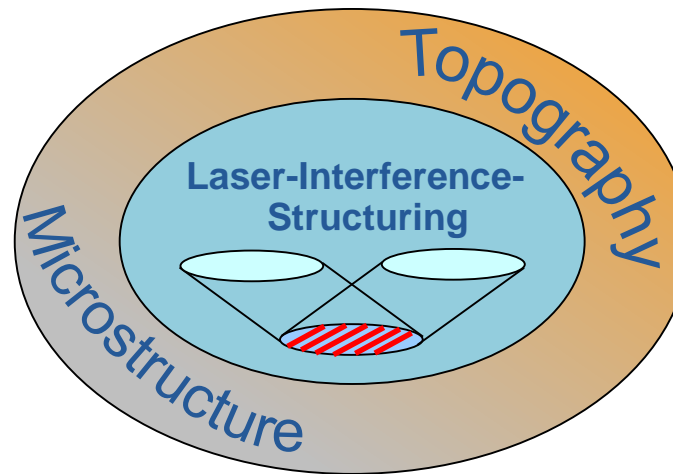
electrical & magnetical properties



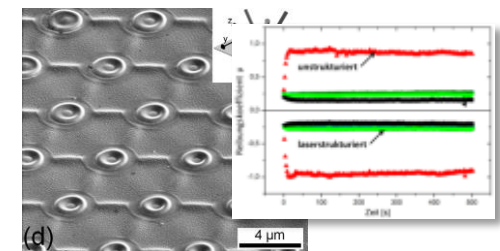
(crystalline/amorphous Ga₂O₃)



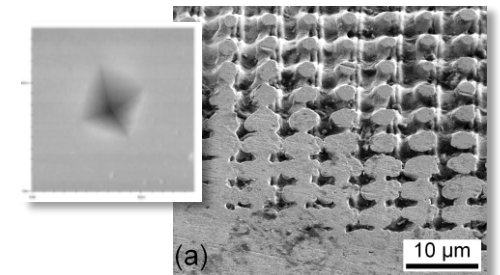
grain architecture



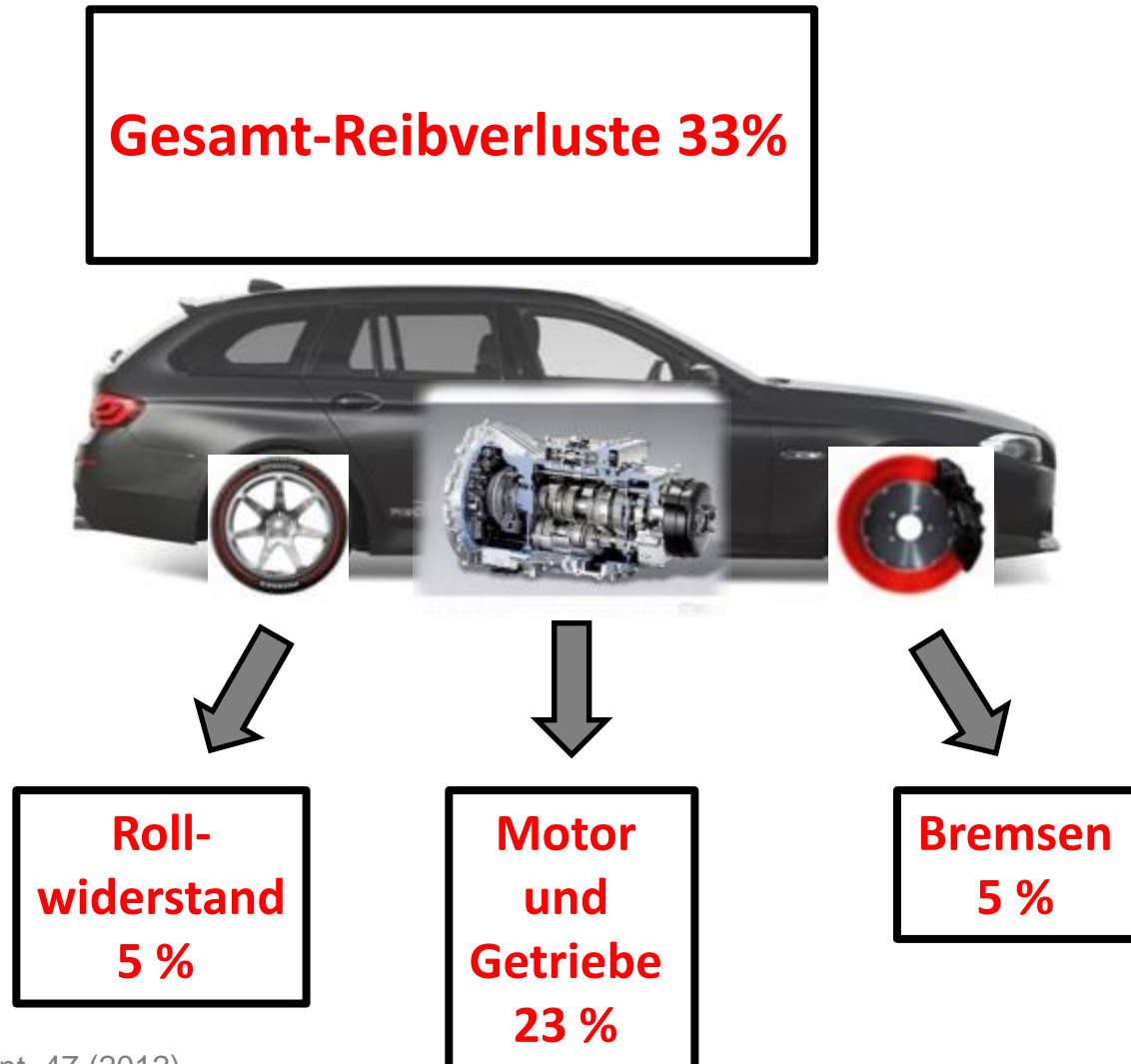
locally induced intermetallics



Tribology, Hardness & Wear



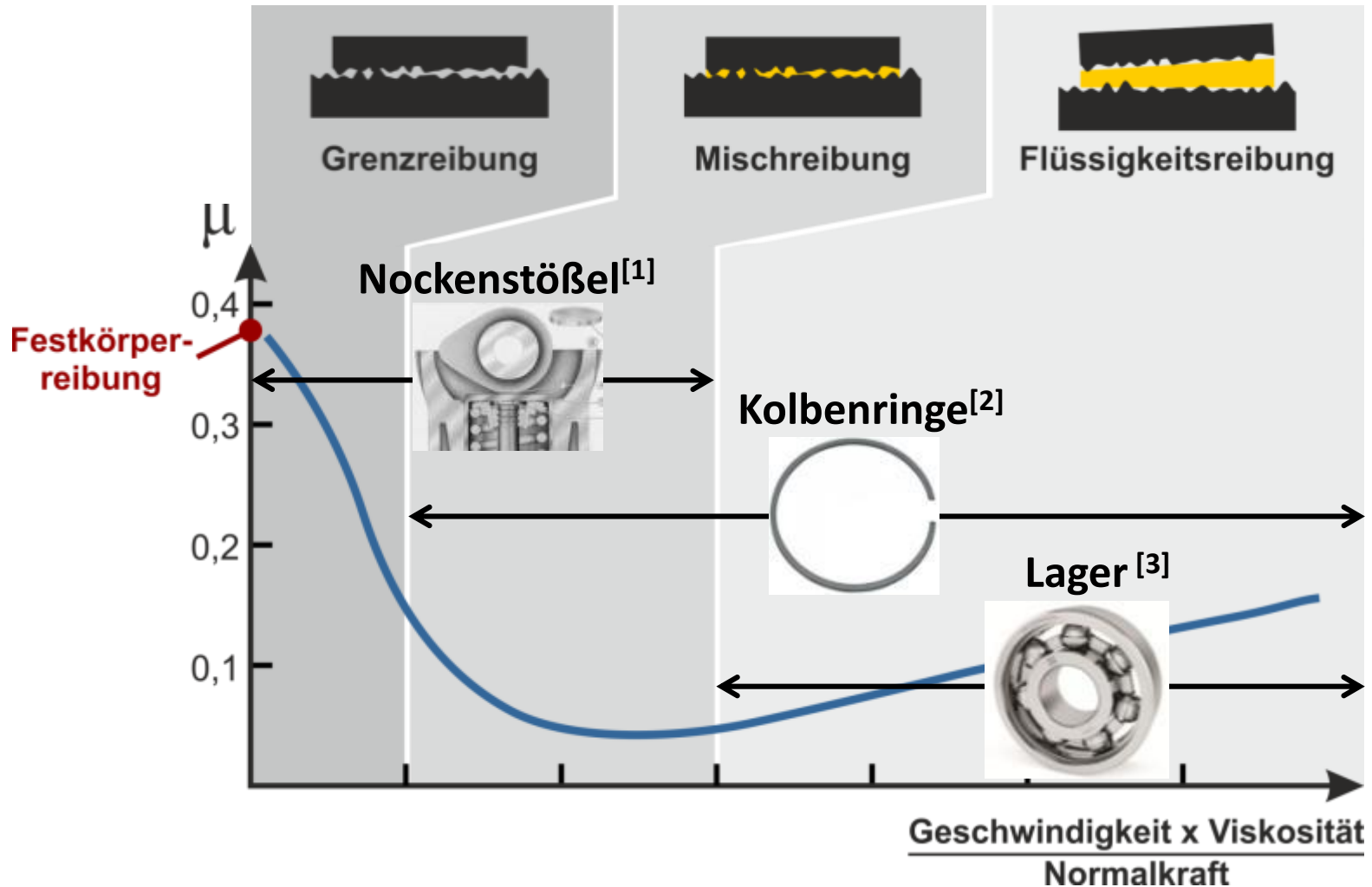
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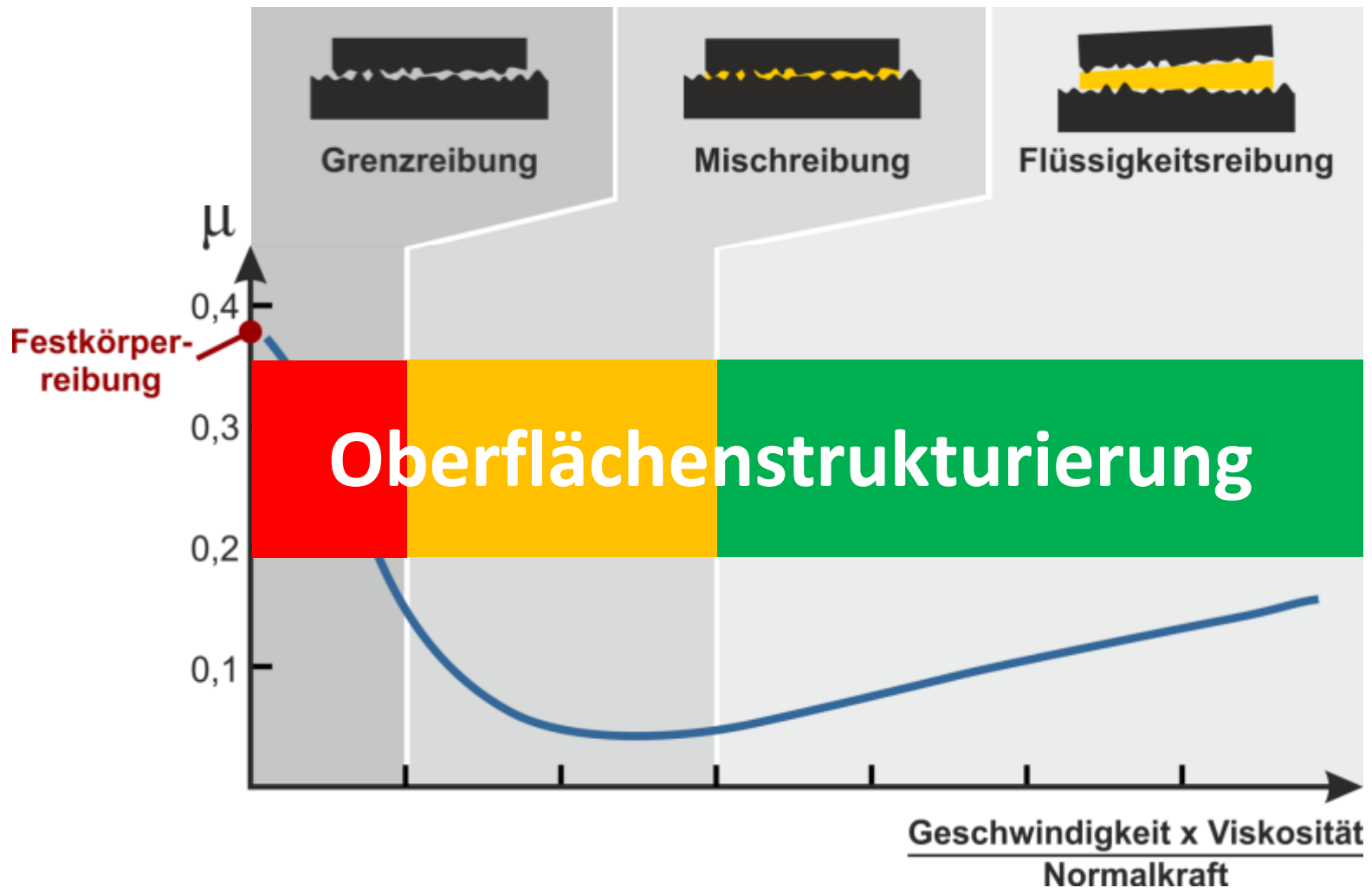
[1] Holmberg et al. Tribol. Int. 47 (2012)

Bildquellen Reifen www.car-point.tv/images/getriebe1.png, Getriebe: www.Auto-bild.de, Bremsscheibe: theonecar.com

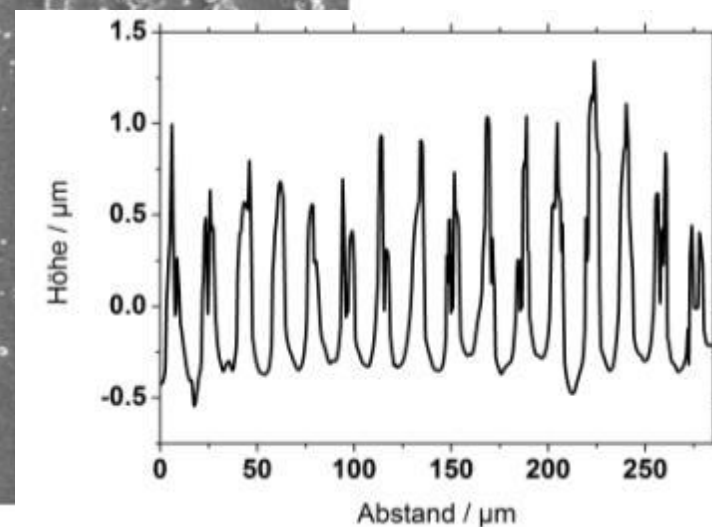
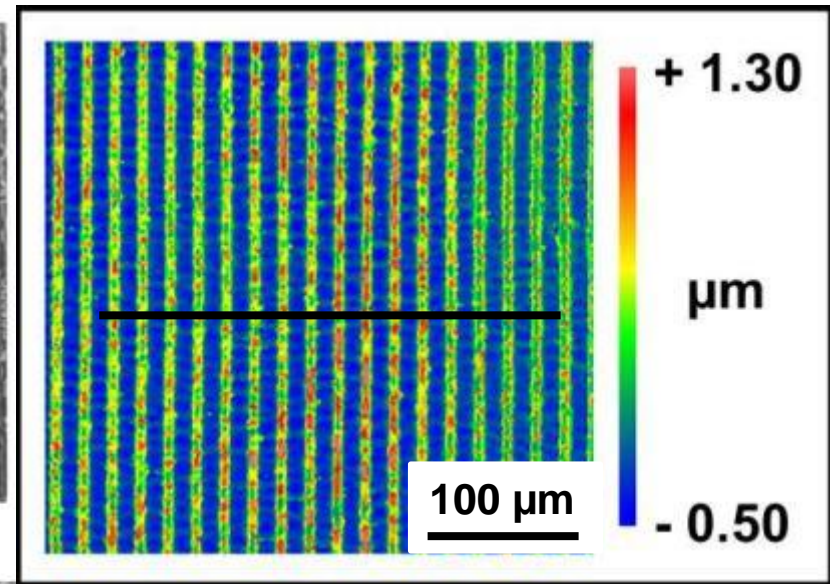
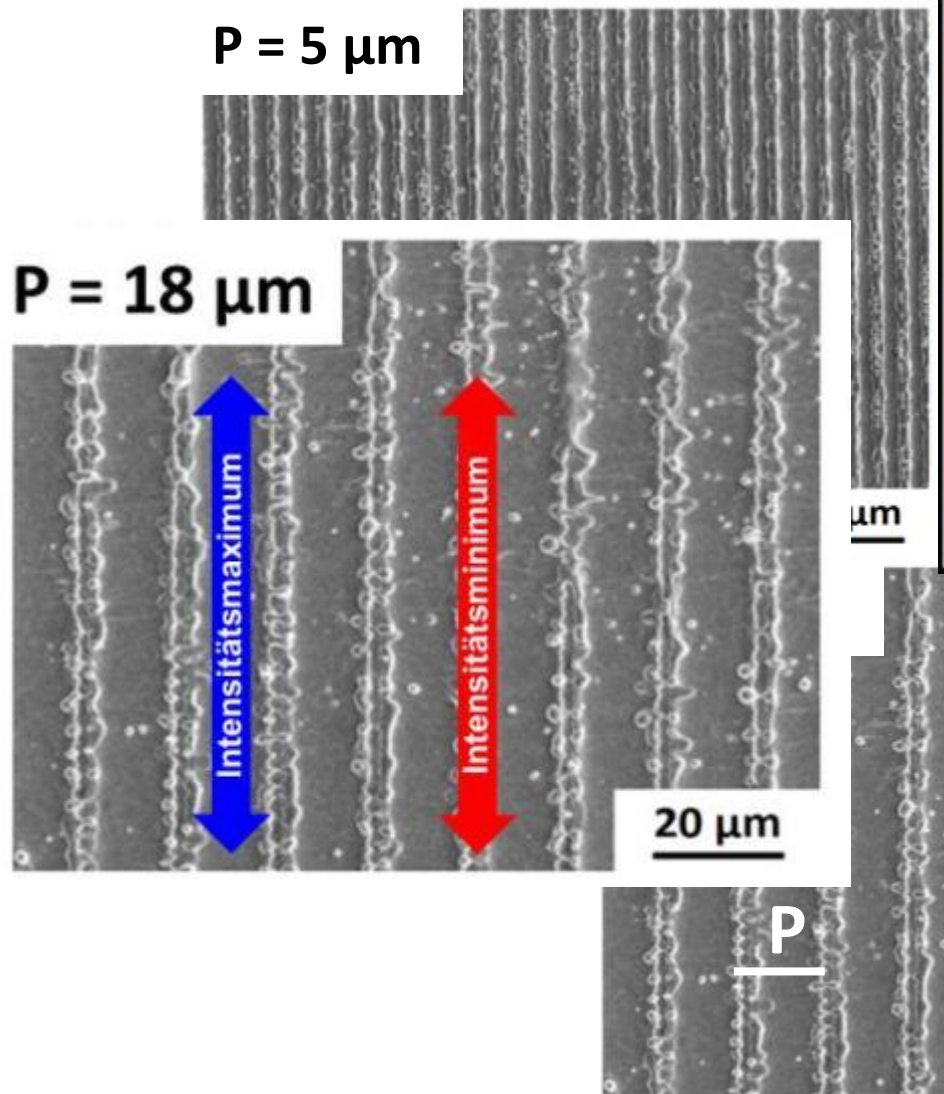
Wie messen wir Reibung? → „Stribeck“-Kurve



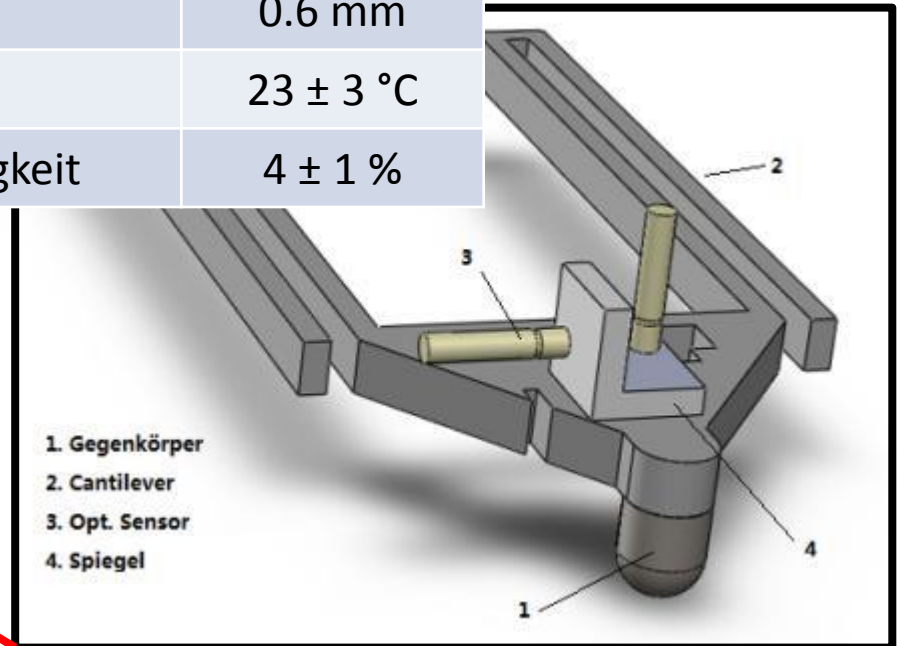
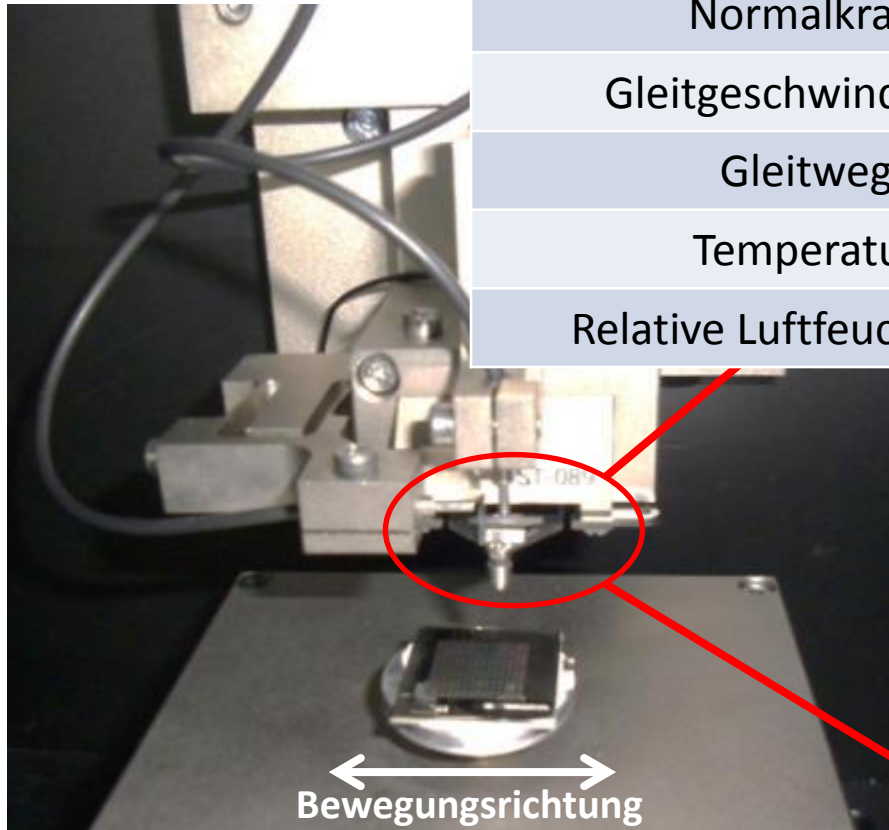
[1] www.mav-online.de [2] www.dahlmann-home.de/images/produkte/i38/3810-kolbenringe.JPG [3] www.troteclaser.com



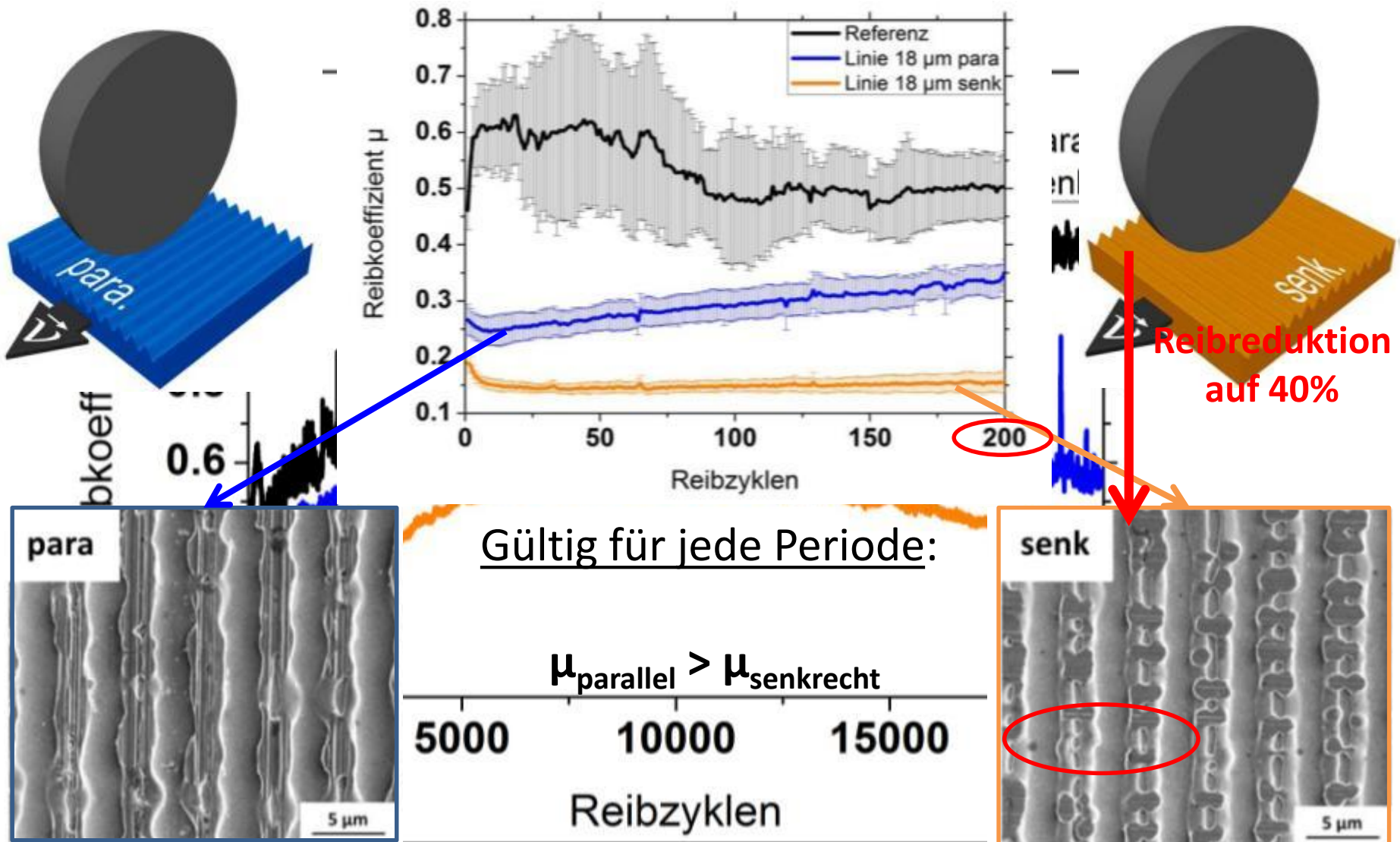
Reibungssteuerung durch definierte Linientopographie



Versuchsparameter	
Normalkraft	1 mN
Gleitgeschwindigkeit	1 mm/s
Gleitweg	0.6 mm
Temperatur	$23 \pm 3 \text{ }^\circ\text{C}$
Relative Luftfeuchtigkeit	$4 \pm 1 \text{ } \%$

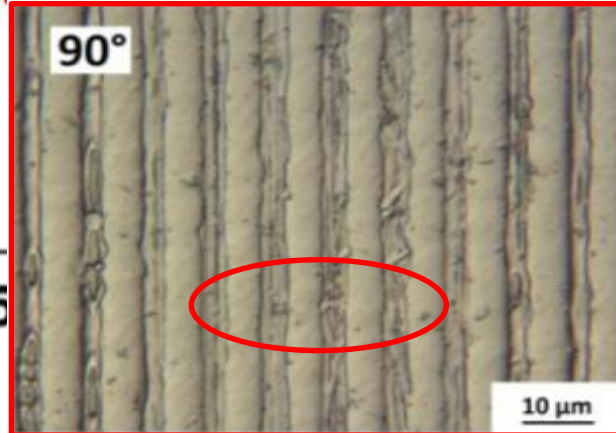
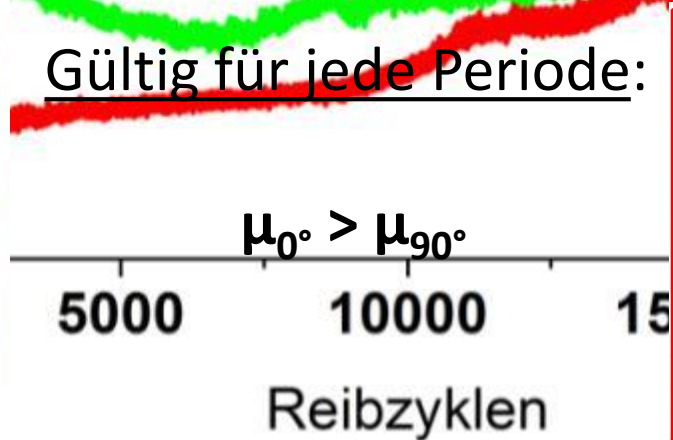
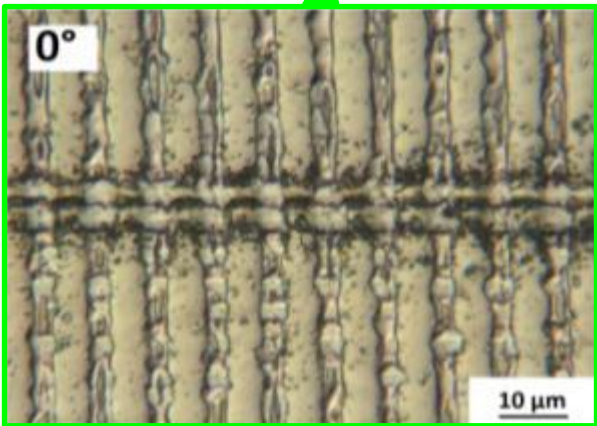
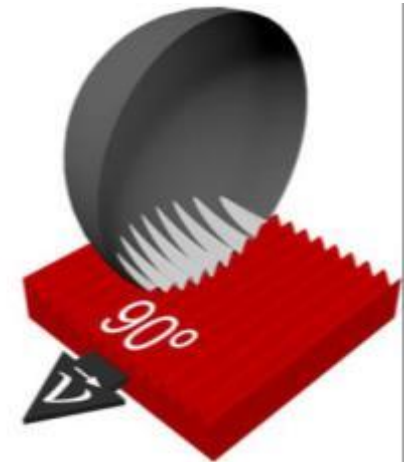
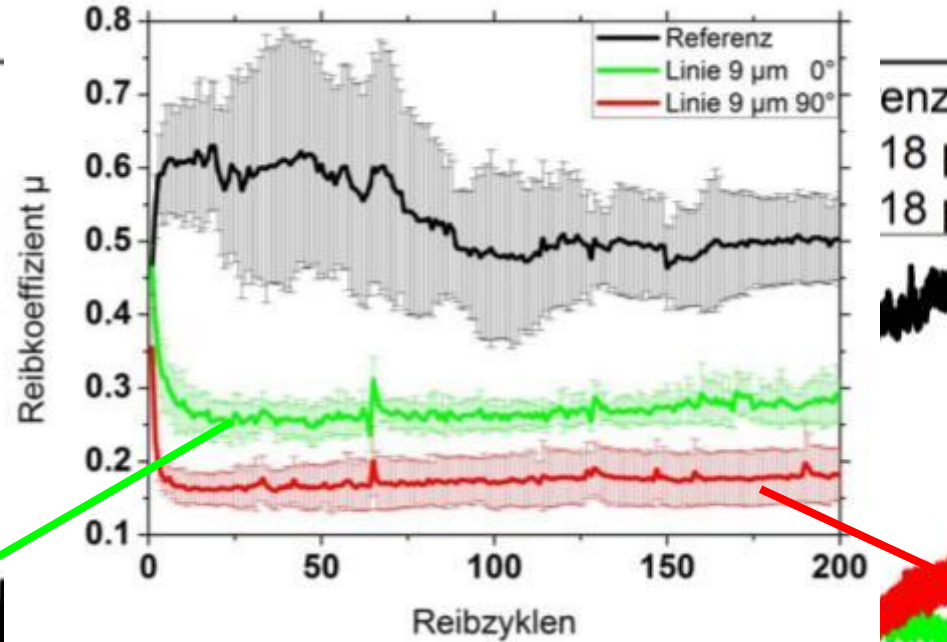
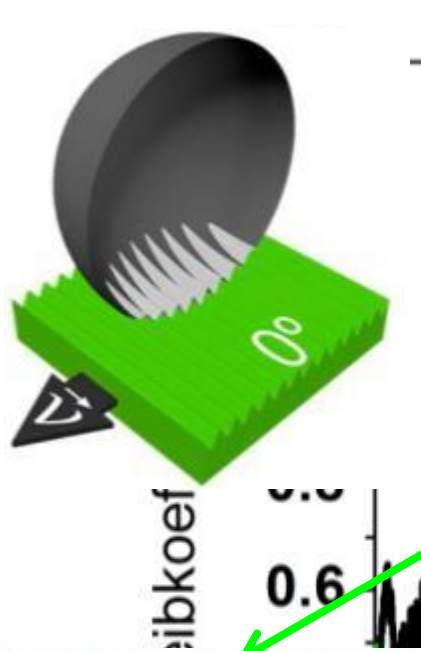


Wie beeinflussen die hergestellten Linienstrukturen das Reibverhalten?



Rosenkranz, Mücklich, Wear 318, 49-61, 2014.

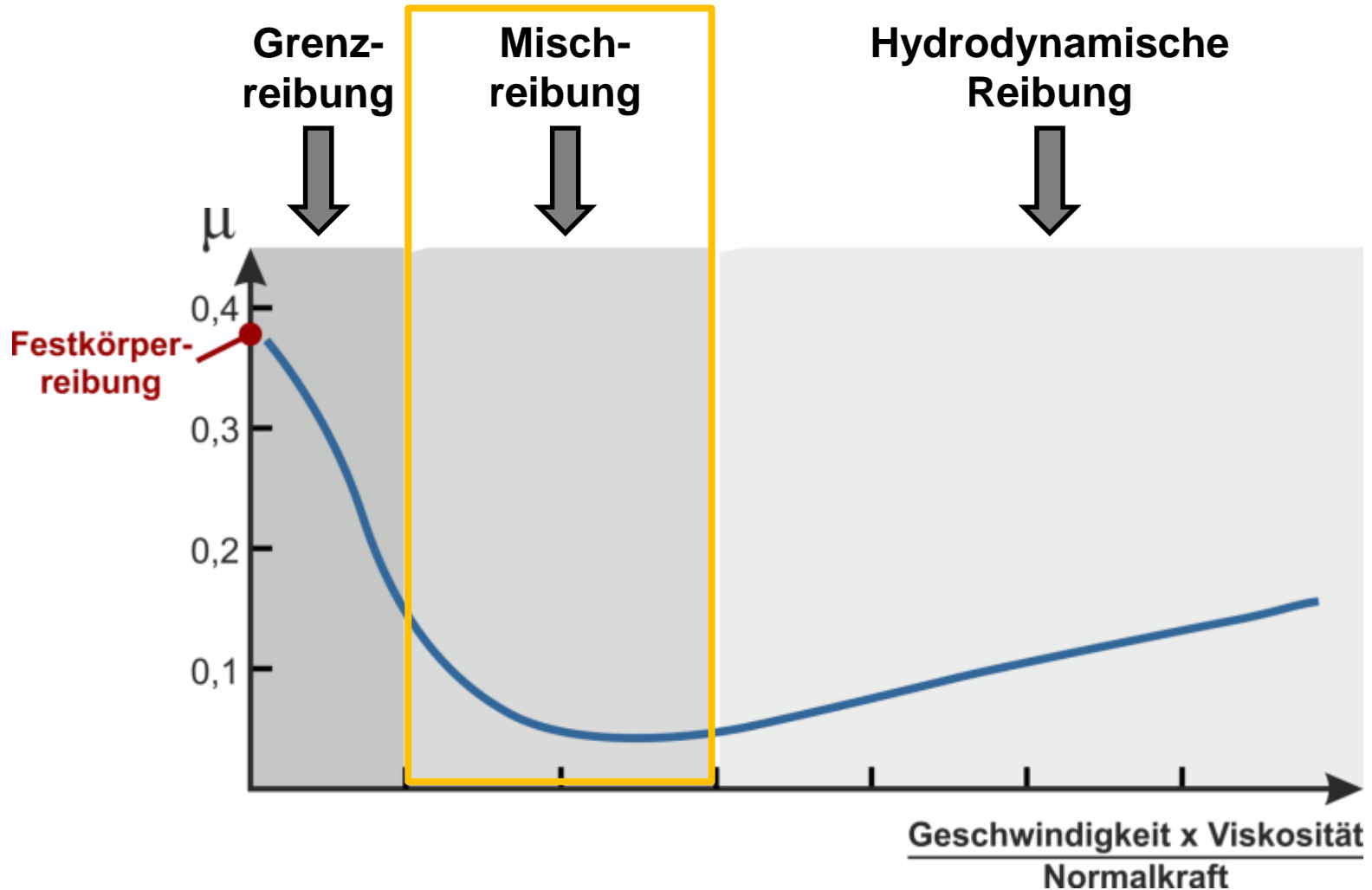
Führt eine beidseitige Strukturierung zu einer gezielten Reibsteuerung?



Rosenkranz, Mücklich, Wear 318, 49-61, 2014.

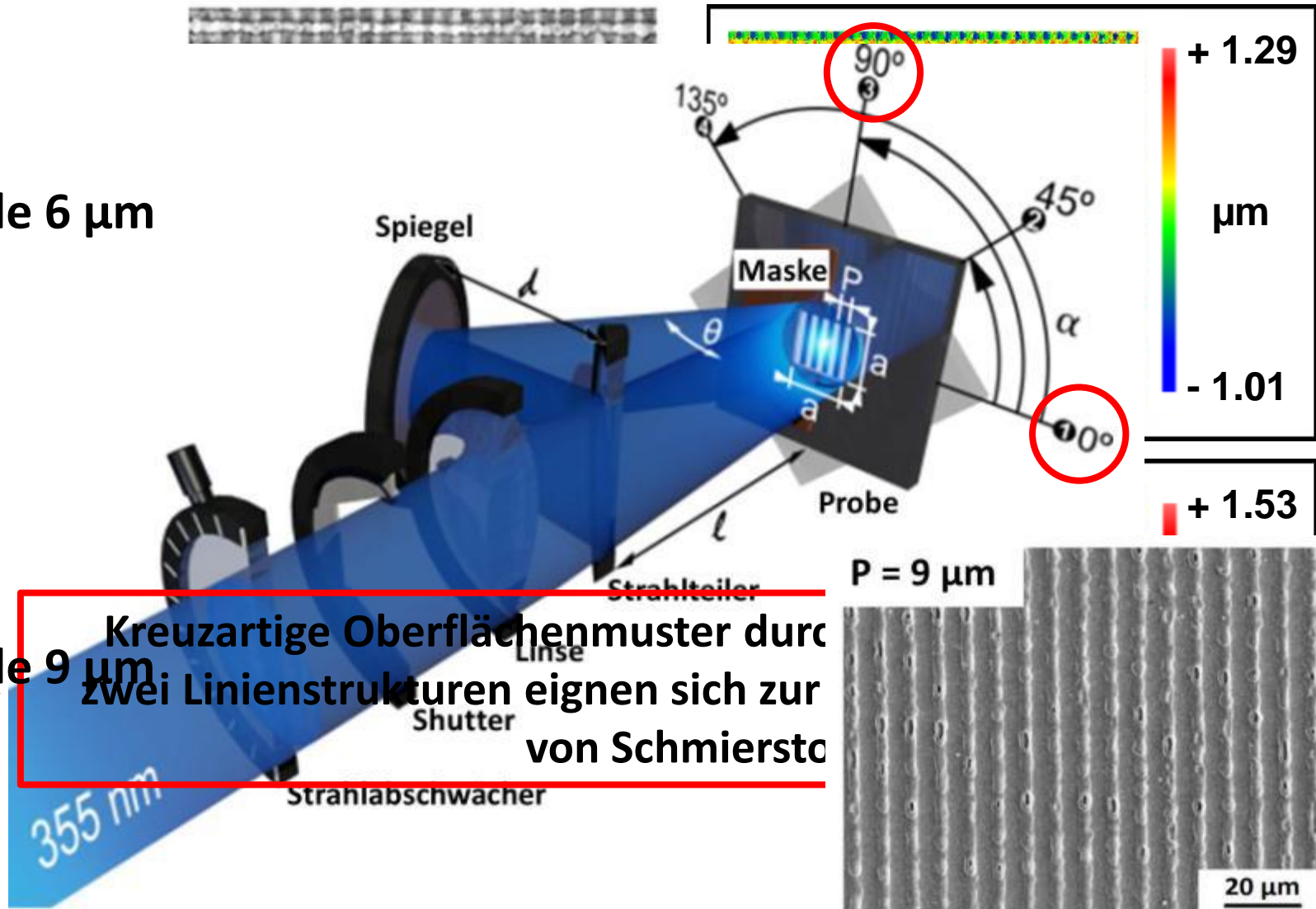
Trocken oder geschmiert? - Mischreibung

→ Stribeckkurve



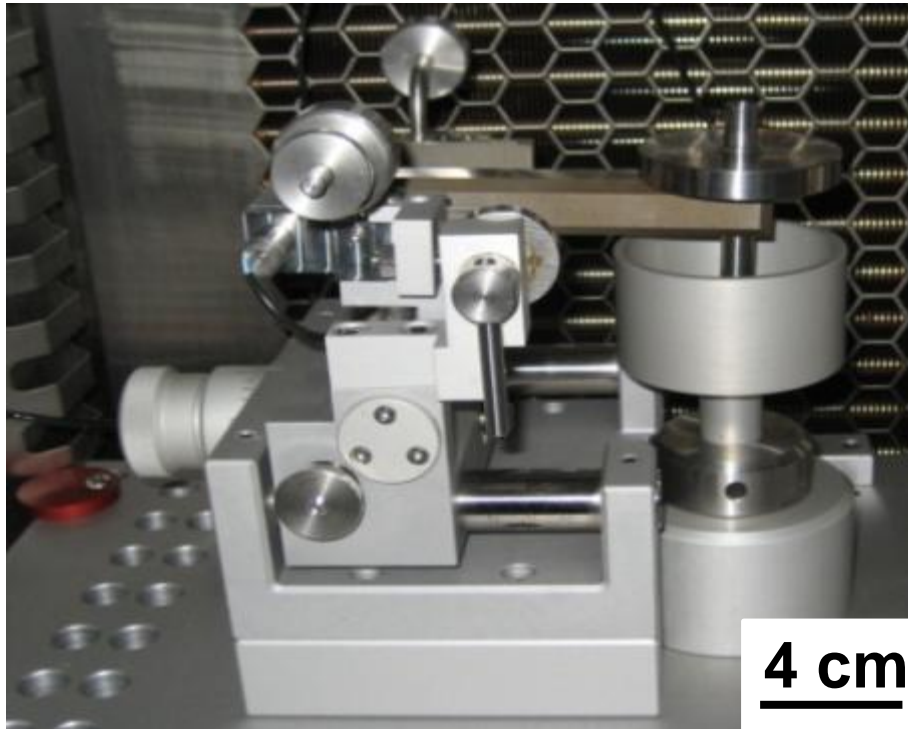
Wie können geschlossene Schmiertaschen hergestellt werden?

Periode 6 μm



Periode 9 μm

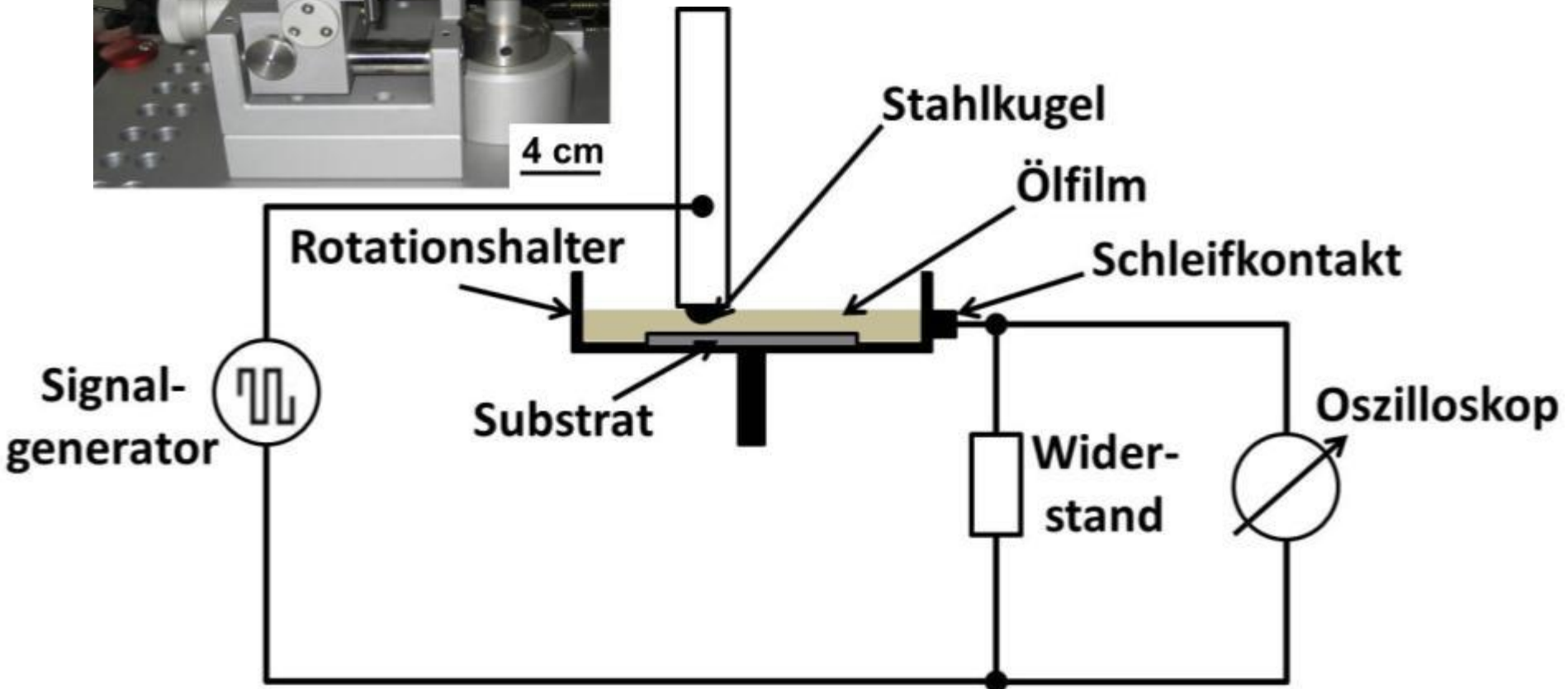
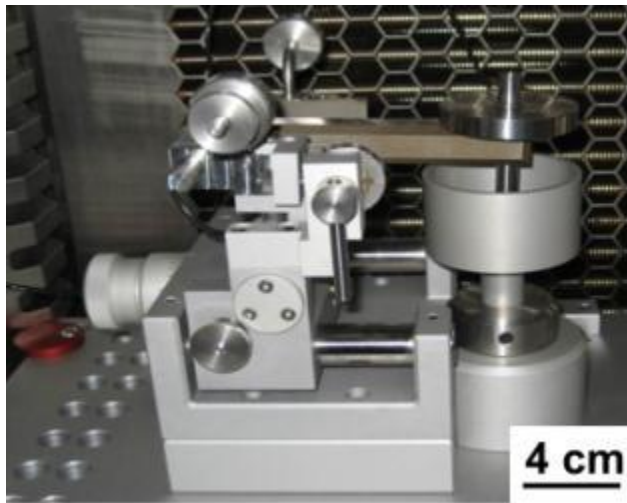
Kreuzartige Oberflächenmuster durch zwei Linienstrukturen eignen sich zur von Schmiersto



Versuchsparameter	
Normalkraft	5 N
Gleitgeschwindigkeit	5 cm/s
Radius	5 mm
Kugeldurchmesser (100Cr6)	6 mm
Schmieröl	PAO 40
Temperatur	$25 \pm 1 \text{ }^\circ\text{C}$
Relative Luftfeuchtigkeit	$45 \pm 2 \%$

Problem: Bestimmen Festkörper-Traganteil

→ unter **Mischreibung**-Bedingungen?

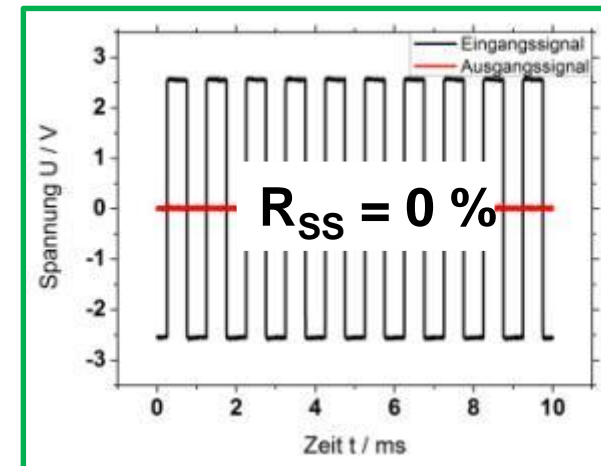
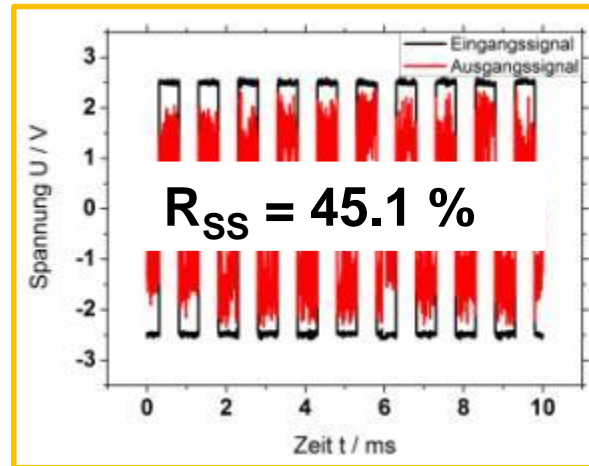
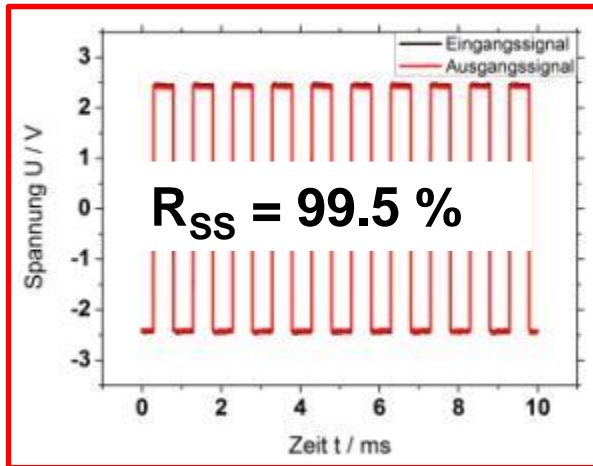
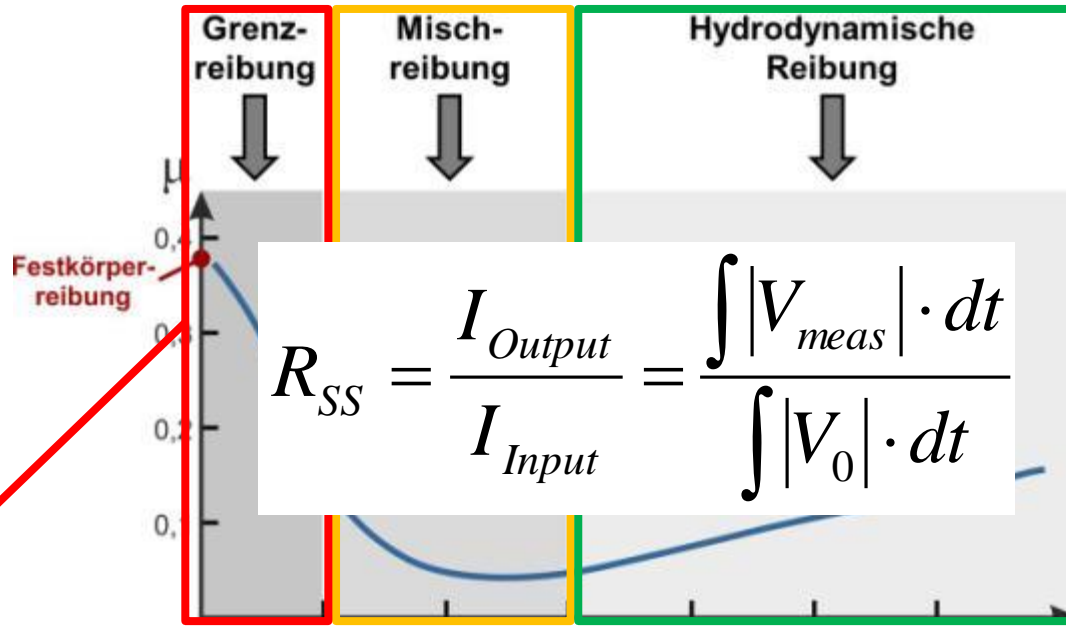


Rosenkranz, Mücklich, Wear 320, 51-61, 2014.

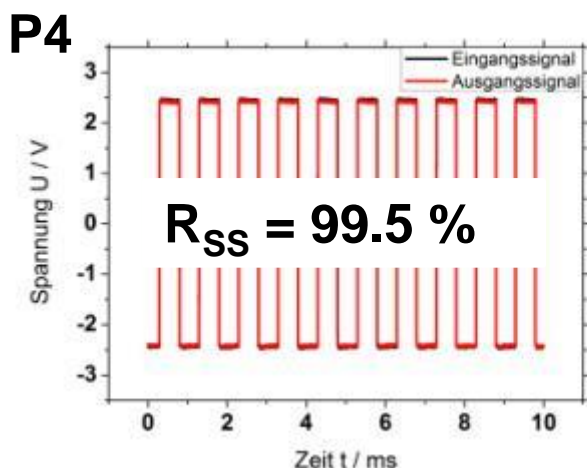
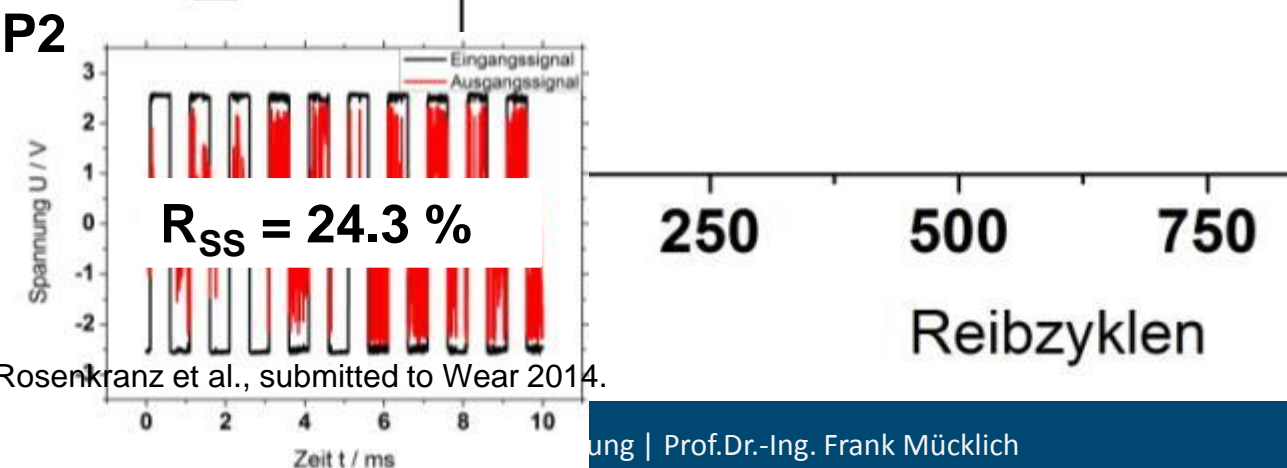
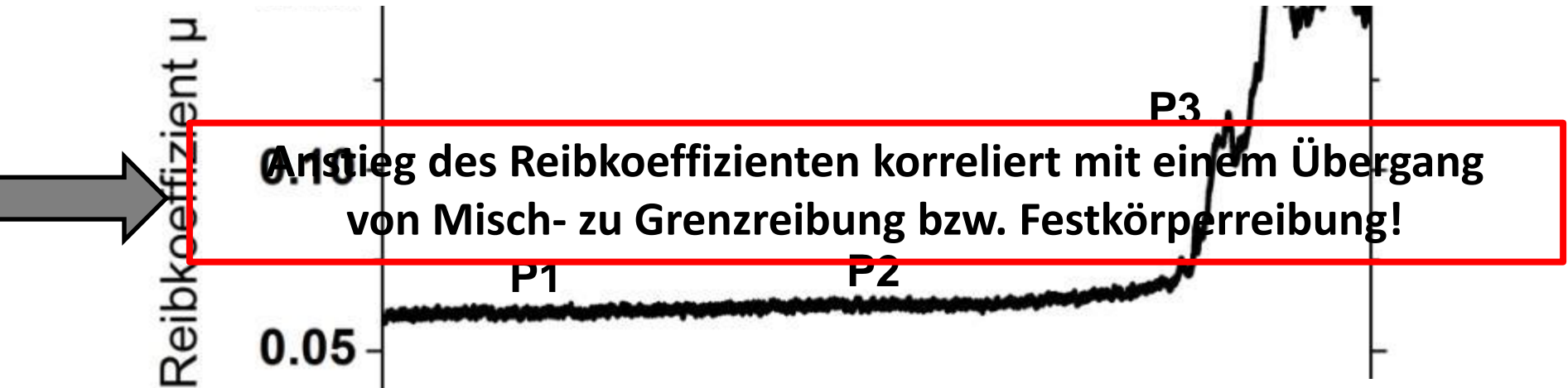
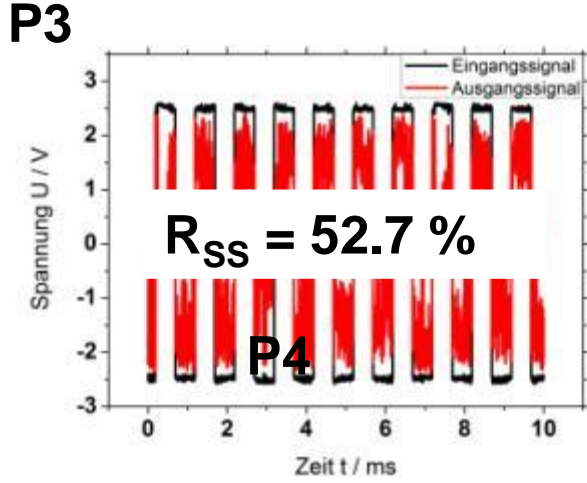
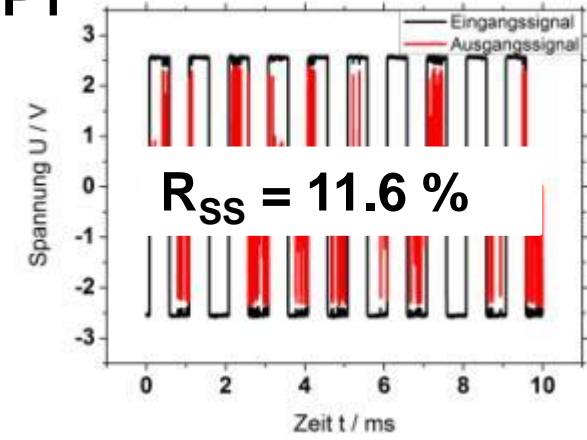
Festkörper-Traganteil

unter Mischreibungsbedingungen

Rosenkranz, Mücklich,
Wear 320, 51-61, 2014.

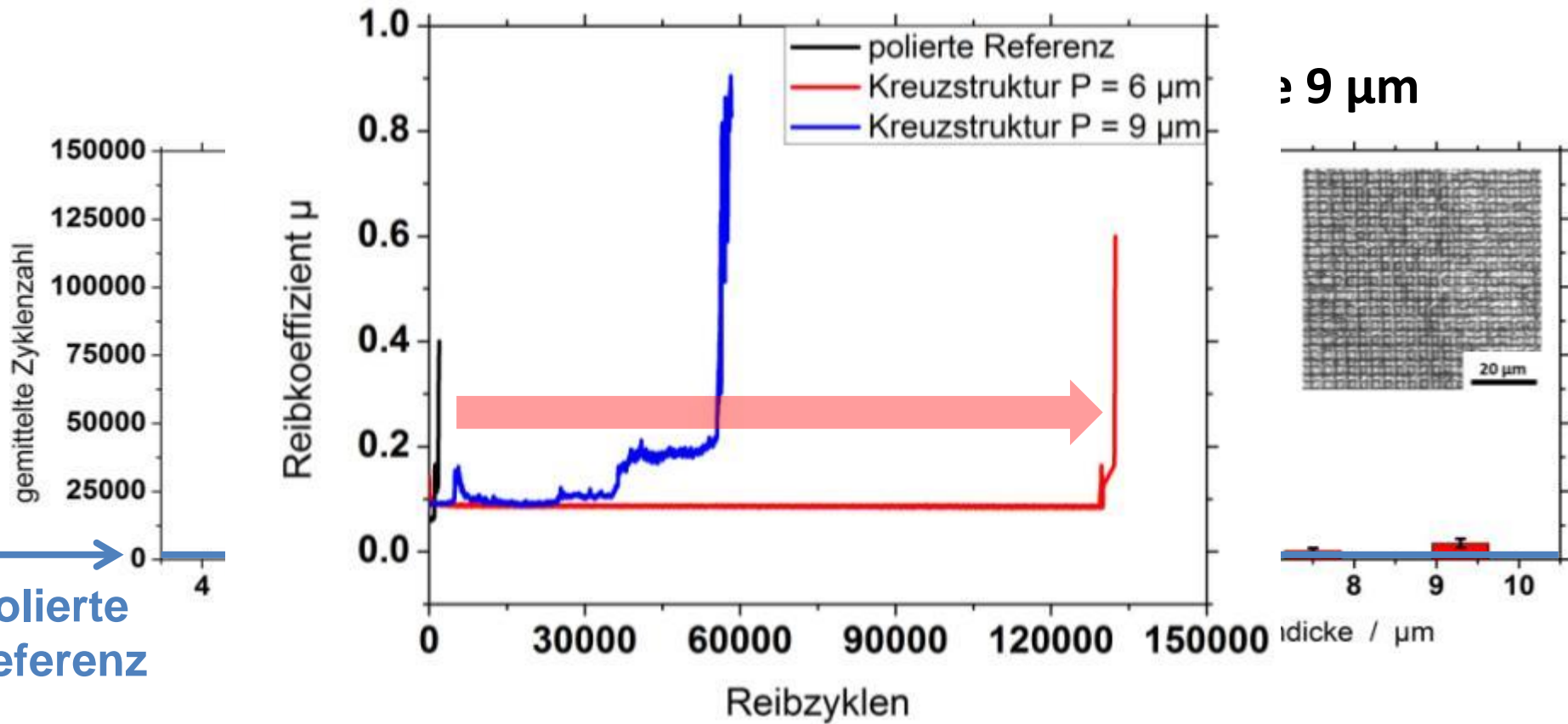


P1 Reibverhalten mit dem signal?



Rosenkranz et al., submitted to Wear 2014.

Welchen Einfluss haben die geschlossenen Schmiertaschen auf die Lebensdauer des Ölfilms?



Polierte Referenz

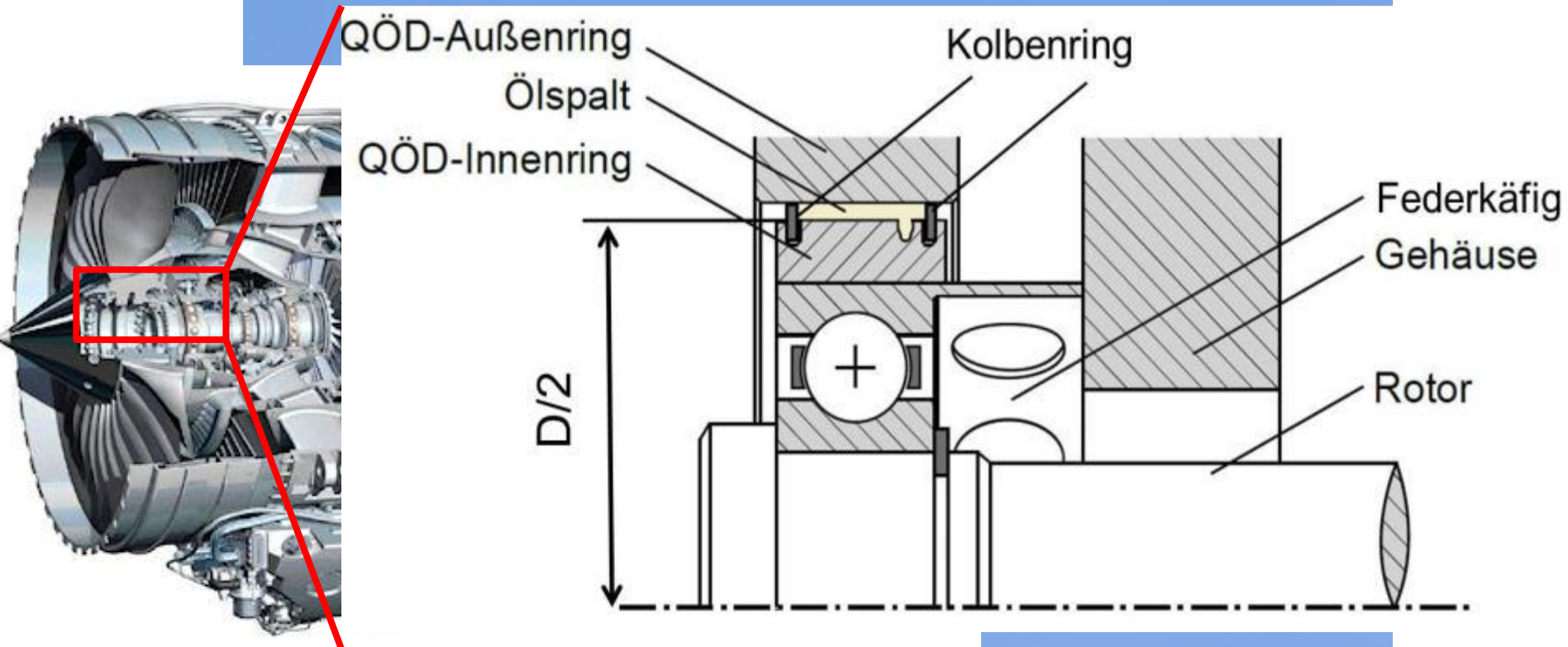
Verlängerung der Ölfilmlebensdauer um den Faktor 130 bei gleich bleibendem Reibkoeffizienten!

Rosenkranz, Mücklich, submitted to Wear 2014.

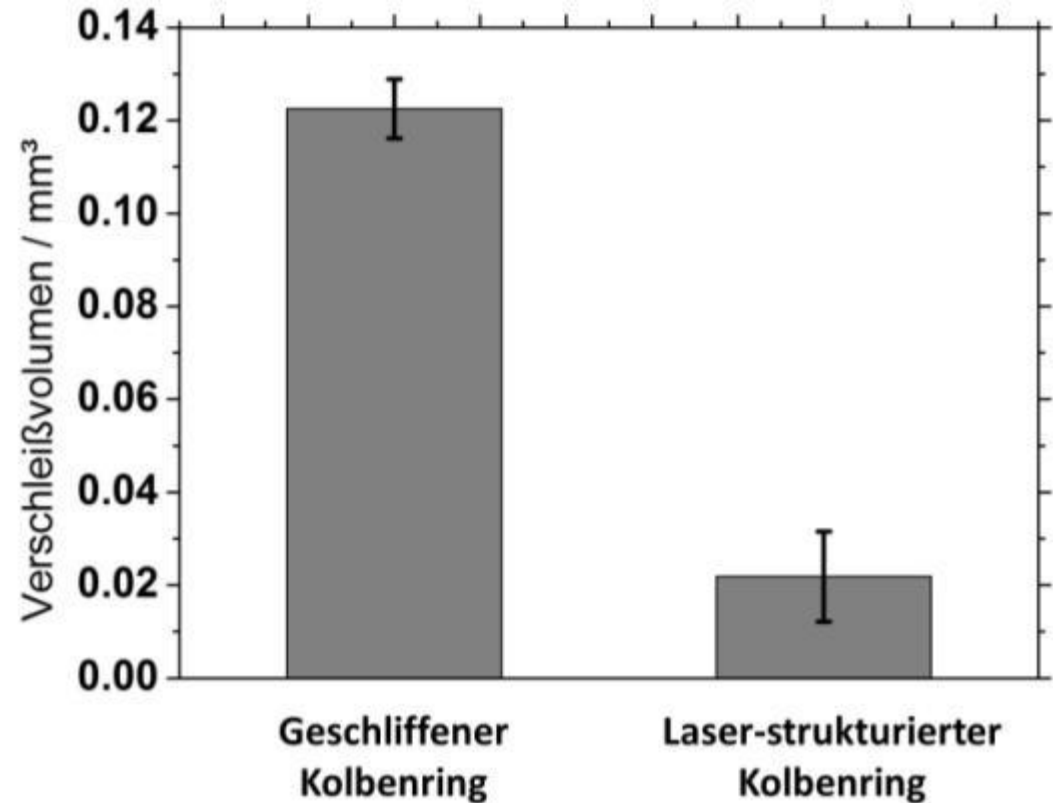
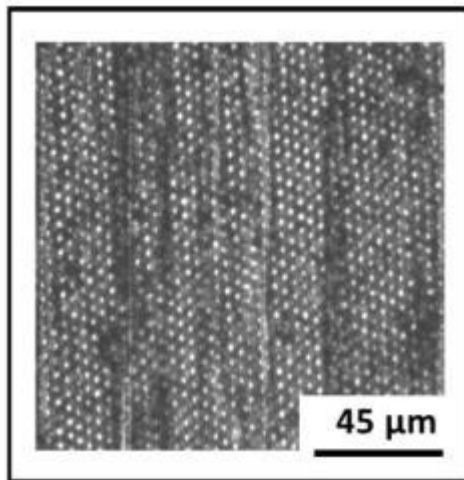
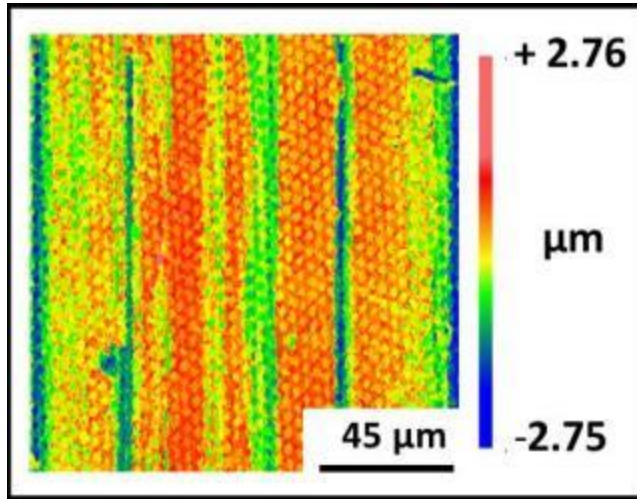
Zwischenfazit – Mischreibung

- ✓ Kreuzartige Oberflächenstrukturen können als **Schmierstoffreservoir** genutzt werden.
- ✓ Kreuzstrukturen mit einer Periode von 6 μm führen zu einer **130-fachen Verlängerung** der Ölfilmlebensdauer bei gleich bleibendem Reibkoeffizienten.
 - ✓ **Gespeicherte Ölmenge**
 - ✓ **Aufbau eines hydrodynamischen Drucks**
 - ✓ **Speicherung der Verschleißpartikel**
- ✓ Verschleißpartikelanalyse bestätigt, dass die Partikel in der Oberflächenstruktur gespeichert werden können (**Verschleißpartikel < Strukturperiode**).

Kolbenring eines Quetschdämpfers in einer Flugzeugturbine



Kolbenring eines Quetschdämpfers in einer Flugzeugturbine



6-fache Verschleißreduktion im realen Konstruktionselement!

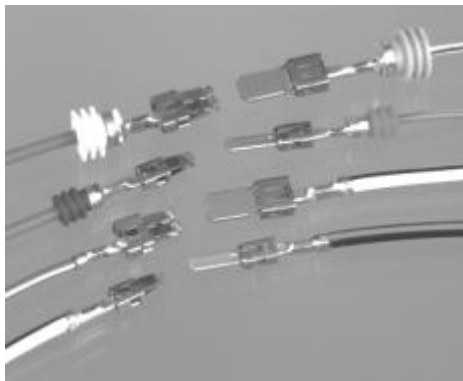
2. Beispiel: Topographiedesign an elektrischen Kontakten

Purpose of connectors:

- Creation of a **separable electrical connection** between two systems

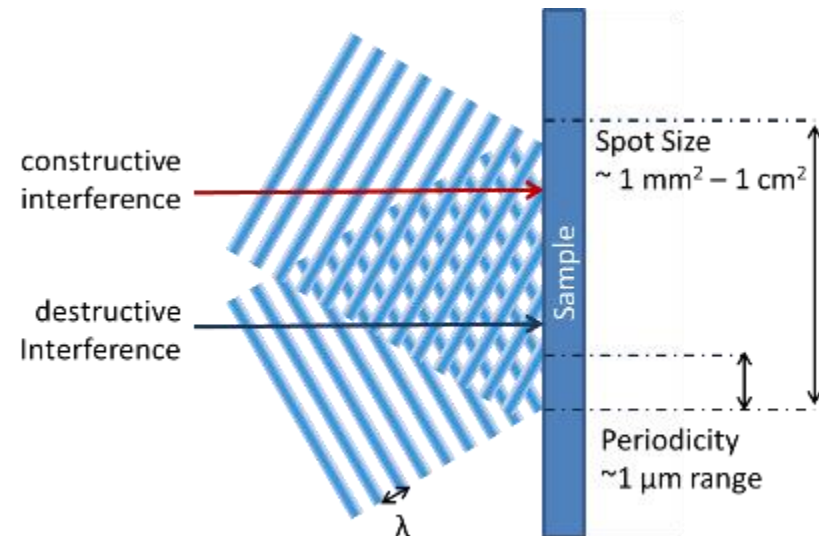
Main requirements on this electromechanical system:

- **Low** and **constant** contact resistance
- **High** wear resistance
- **Low** and **stable** insertion-/withdrawal forces



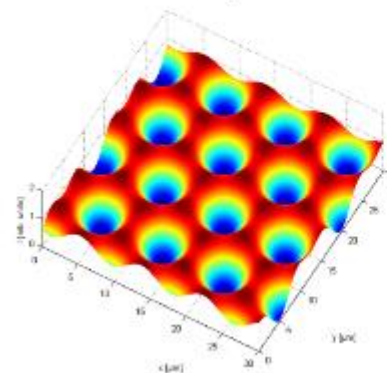
Flat contact systems for automotive applications
[www.te.com]

Laser Interference Principle:

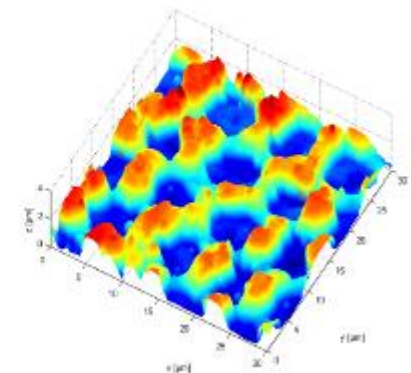


3 beam laser interference

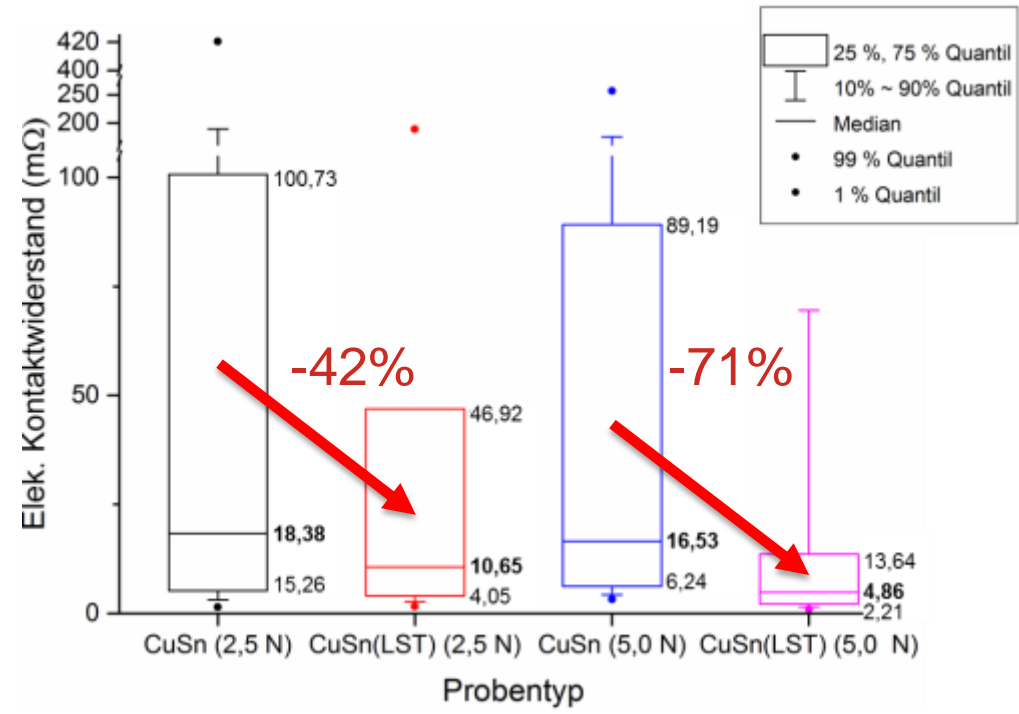
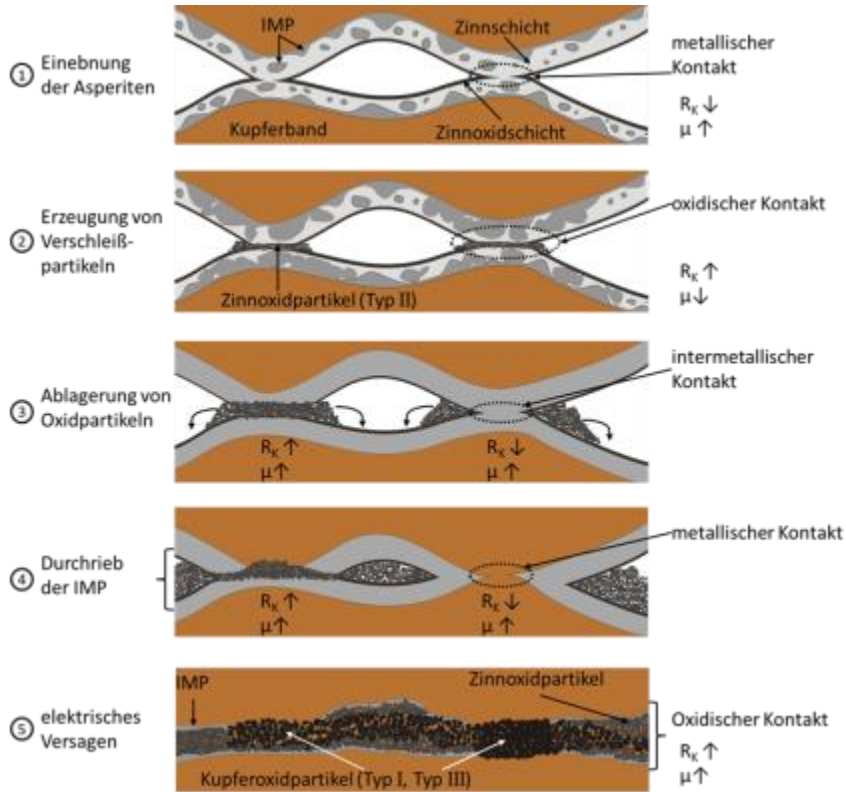
Calculated intensity distribution



real surface from AFM measurement

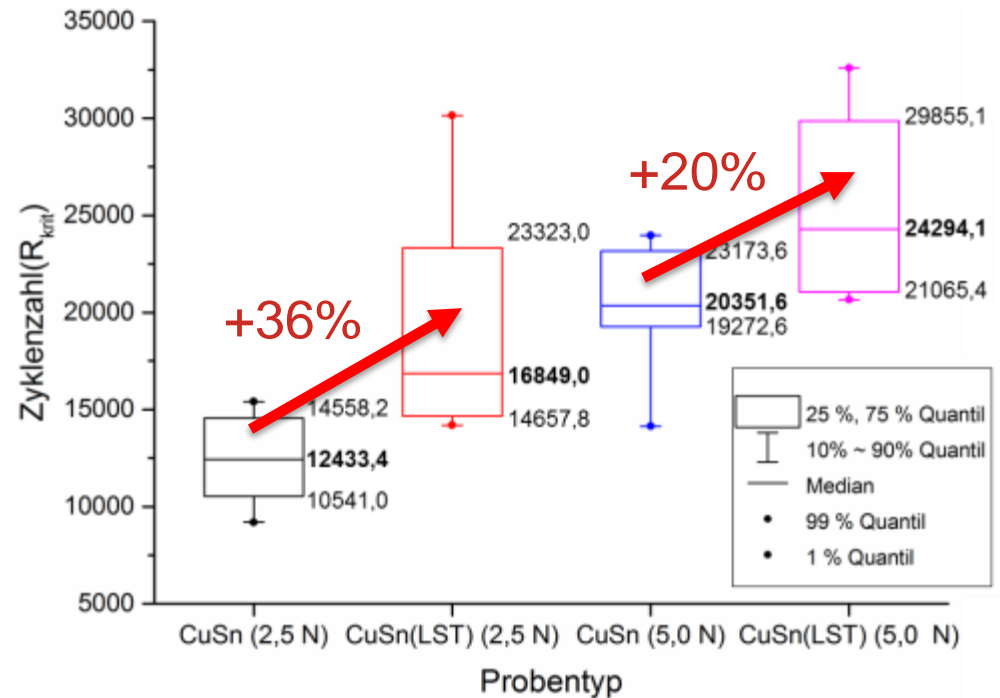
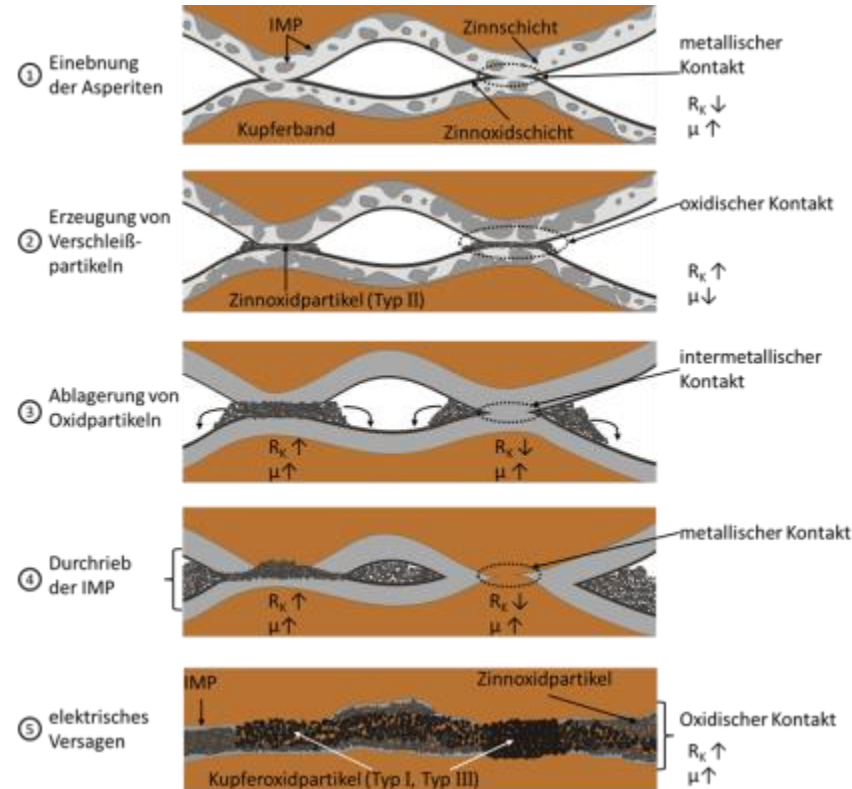


Zuverlässige Verringerung des dynamischen Kontaktwiderstandes bei Fretting-Belastung: **40-70%**

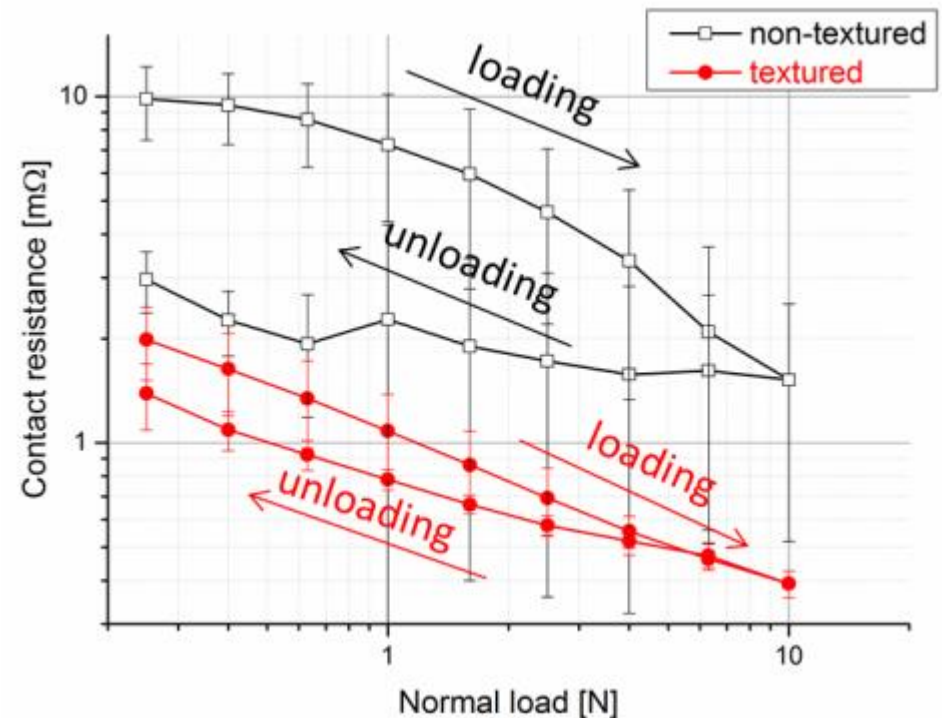
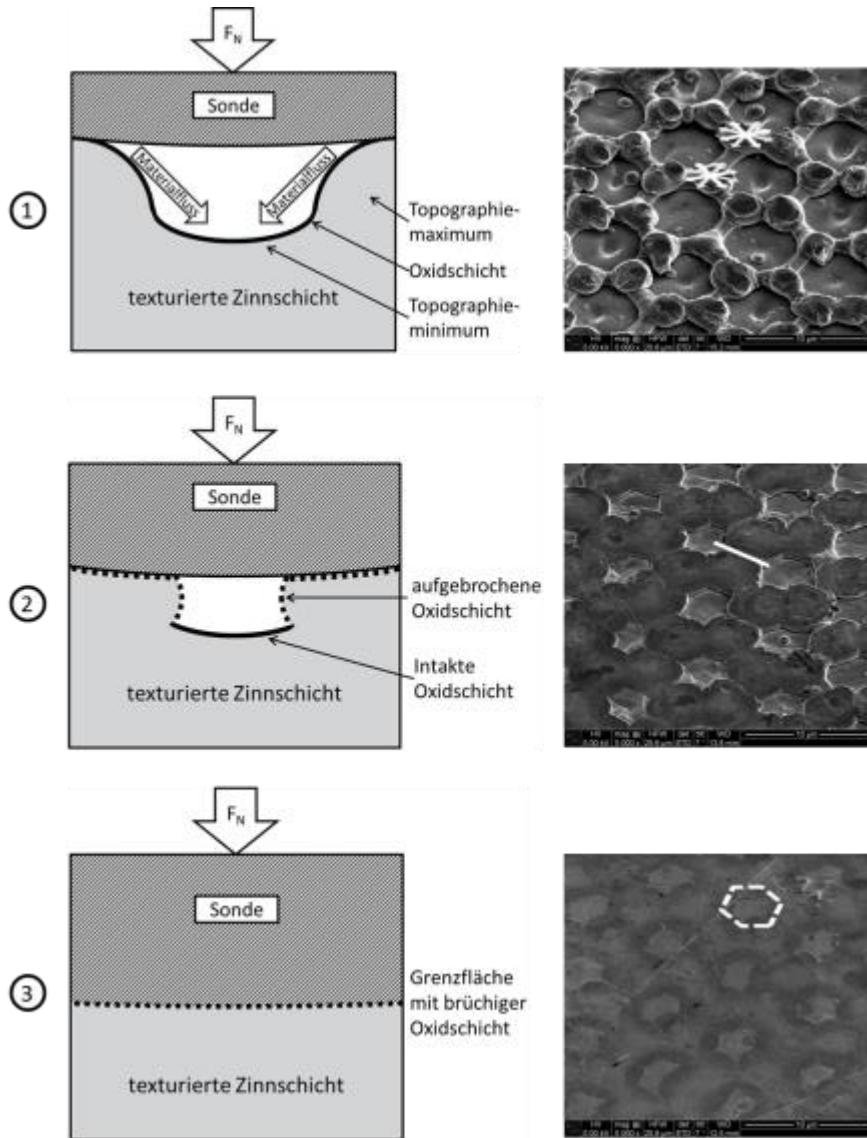


Zuverlässige Erhöhung der Zyklenzahl

→ mehr als 20% bei Fretting-Belastung



Reduzierung des Kontaktwiderstandes bei statischem Kontakt um **mehr als 80%**



3. Beispiel: Wachsendes Problem - Steigende mikrobielle Resistenz gegen Antibiotika

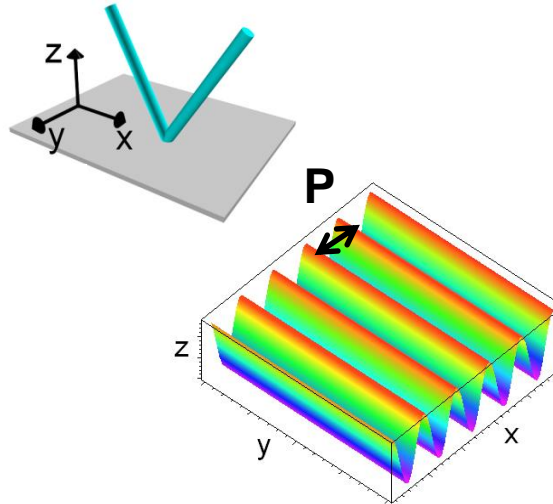
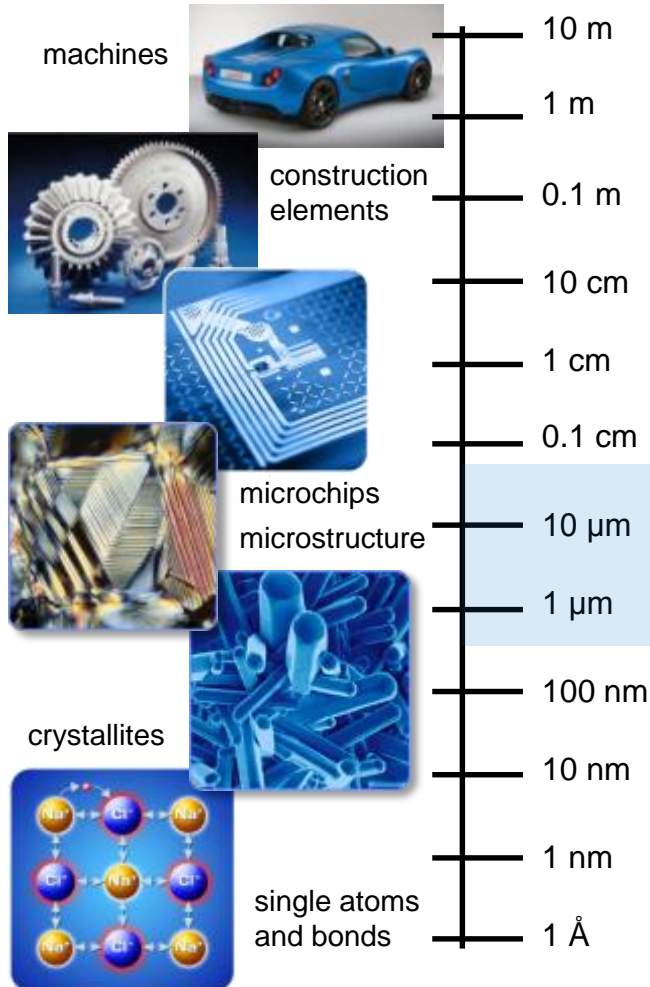


Antimicrobial Resistance Surveillance Report, ecdc, 2011

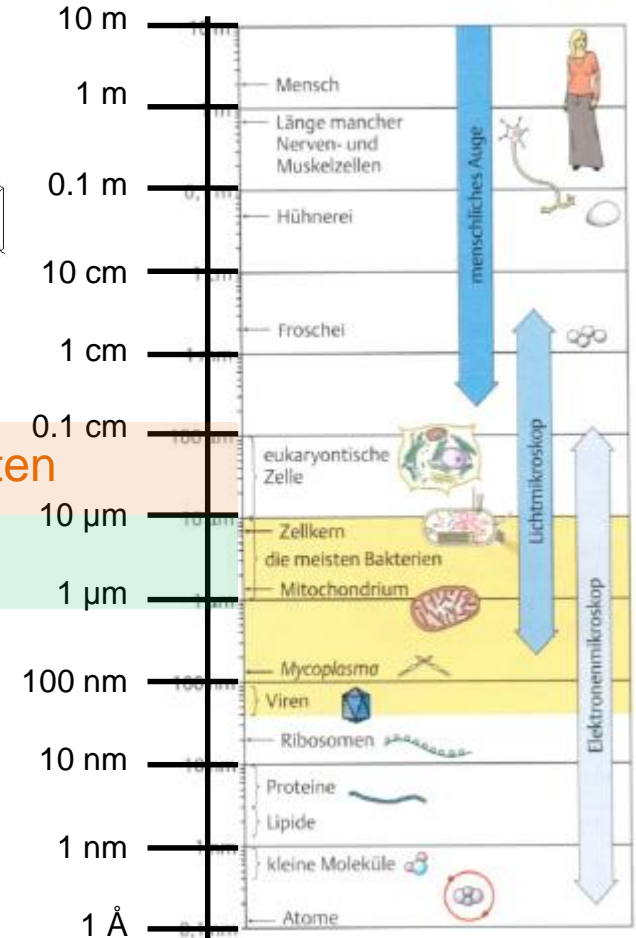


Laser Oberflächenstrukturierung skaliert mit biologischen Dimensionen

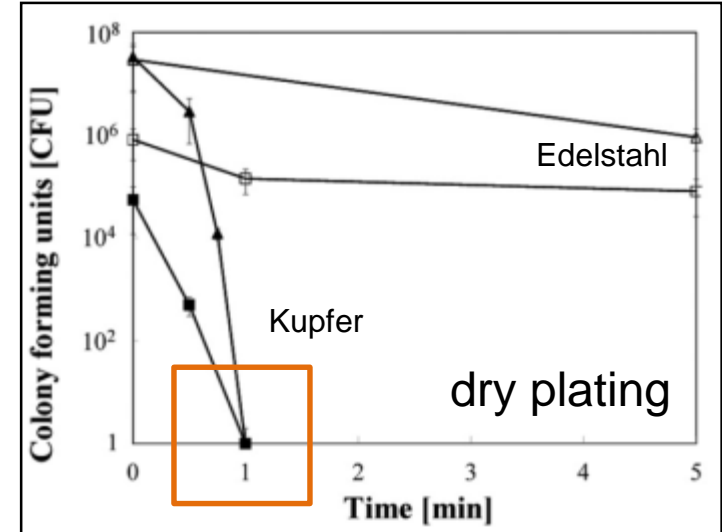
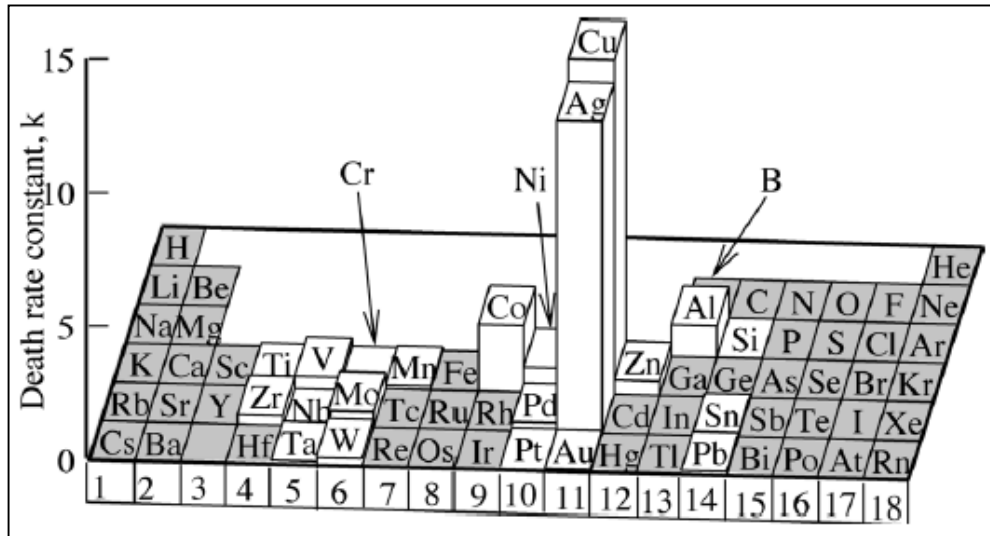
Materials Science



Biology



S. aureus on laser patterned copper surface



- Kupfer **biokompatibler** als Silber? (essentielles Spurenelement)
- Silberoxid = eigentliche, antimikrobielle Verbindung
generell wirksamer in flüssigem Umfeld
- Kupfer generell **wirksamer** in **trockenem** Umfeld

H. Kawakami et al. *ISIJ International* 48, 1299-1304 (2008)

S.L. Warnes, C.W. Keevil, *Appl. Environ. Microbiol.* 77(17), 6049–59 (2011)

J. Gibbard, *Amer. J. Pub. Health* 27(2), 112–9 (1937)

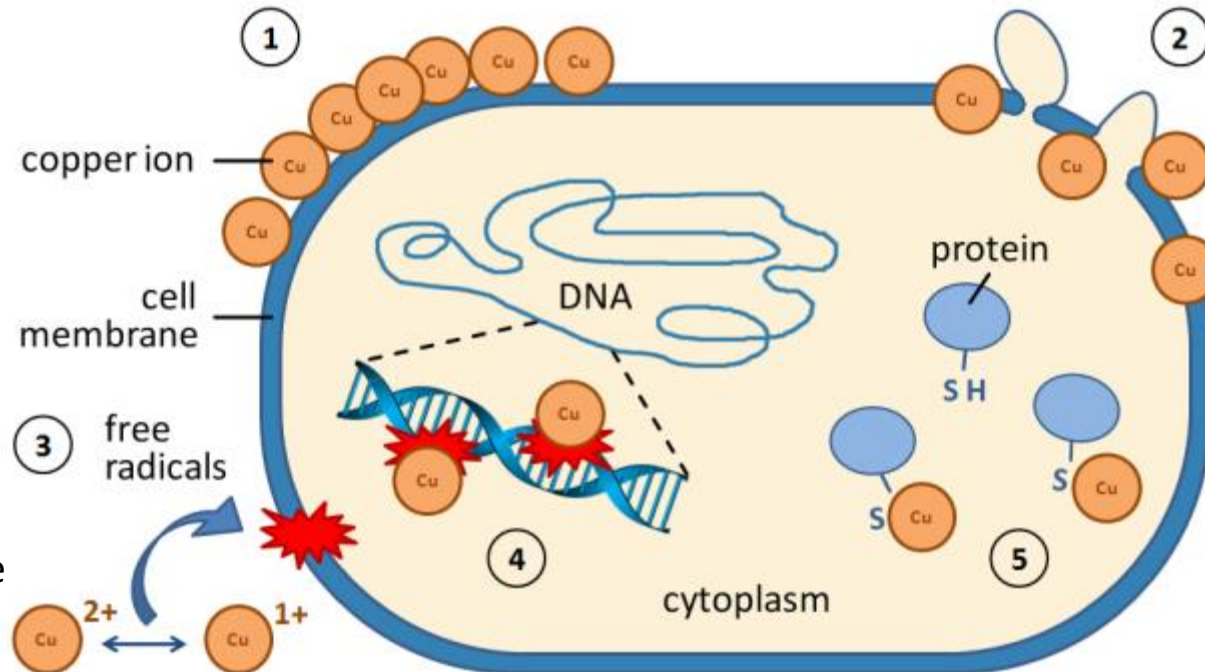
C. E. Santo, E.W. Lam, C.G. Elowsky, D. Quaranta, D.W. Domaille, C.J. Chang, G. Grass, *Appl. Environ. Microbiol.* 77(3), 794–802. (2011)

State of the Art: Microbiology

Multiple Mechanisms of Toxicity for Cu-Ions

1. adsorption to membrane,
bacteriostatic effect

2. degradation and
leakage of cell membrane



3. redox-reactions
generate aggressive
free radicals

4. substitutional
addition to DNA

5. damage to cell metabolism
through alteration of proteins

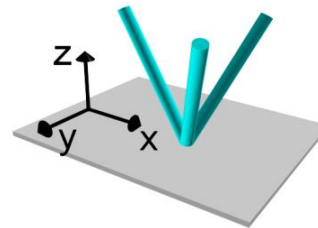
Reviews on the subject: G. Borkow et al. *Cur. Medicinal Chem.* 12, 2163-2175 (2005), & 6:2, 93-103 (2012)

Laser Interference Lithography

spin coating

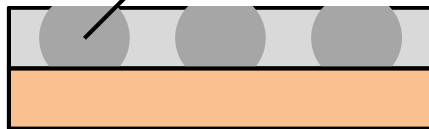
1

AZ 1518 photo resist
polished Cu



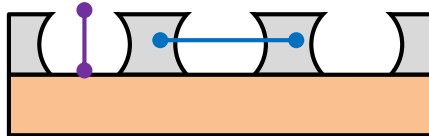
exposed areas become solvable
after Laser Interference Patterning

2

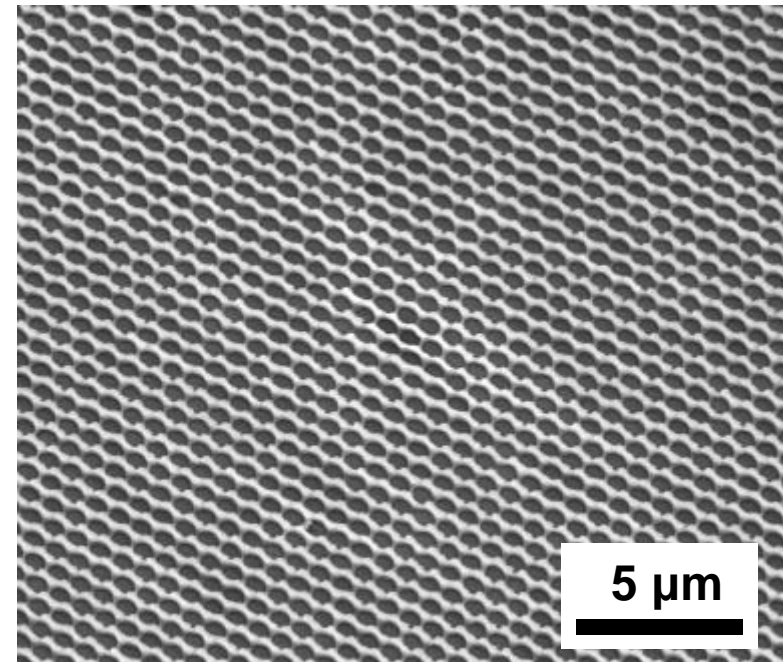
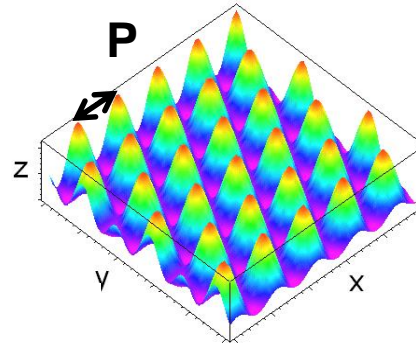


developing of photo resist

3



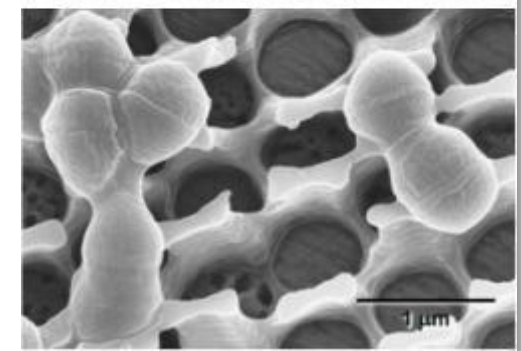
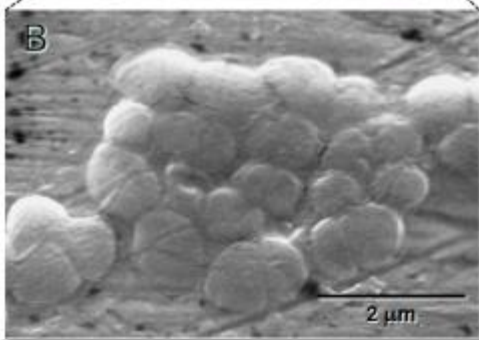
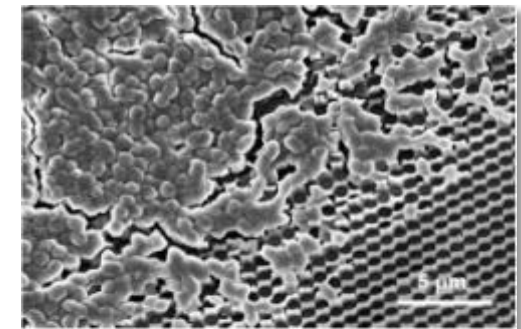
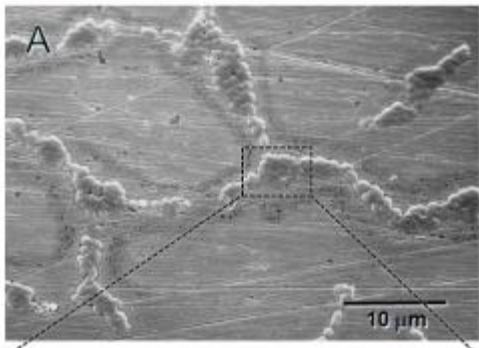
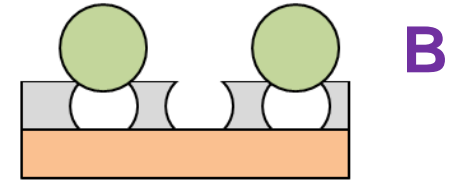
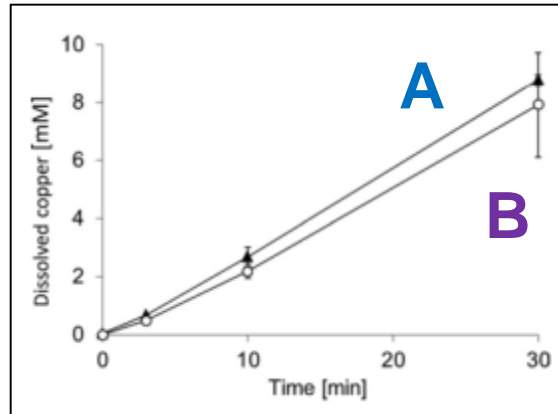
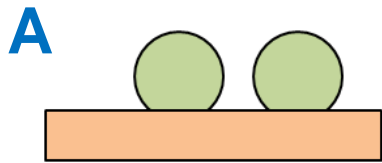
$H = 1.75 \mu\text{m}$ $P = 880 \text{ nm}$



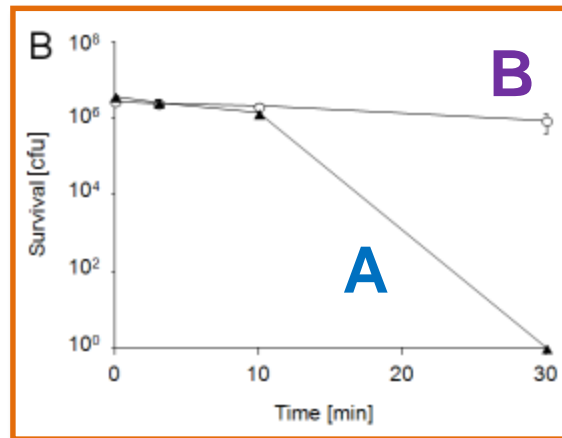
S. Mathews, M. Hans, F. Mücklich, M. Solioz, *Appl. Environ. Microbiol.* 79:8, 2605-11 (2013)

“Contact” Killing

equal ion release



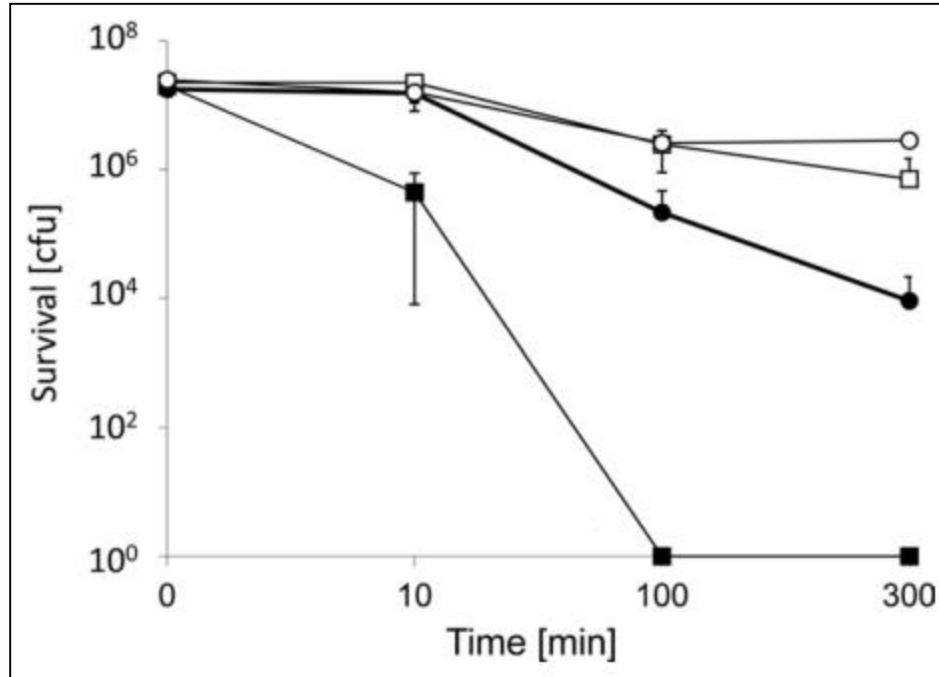
surprising killing behavior



S. Mathews, M. Hans, F. Mücklich, M. Solioz, *Appl. Environ. Microbiol.* 79:8, 2605-11 (2013)

“Contact” Killing on various surfaces

verification, 2nd experiment



glass

Fe

glass + 4 mM CuSO₄

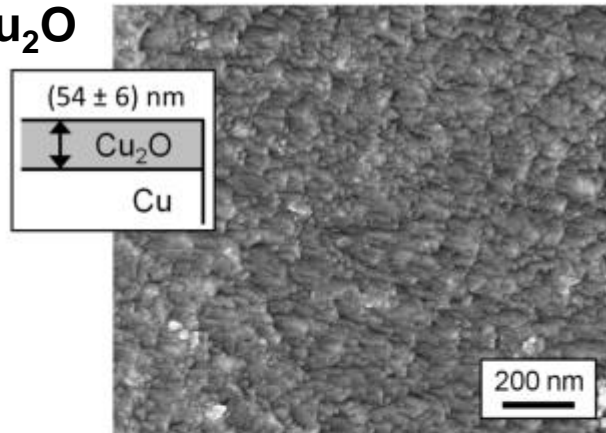
Fe + 4 mM CuSO₄

- killing factors: ✓ presence of Cu-ions
✓ contact to metallic surface

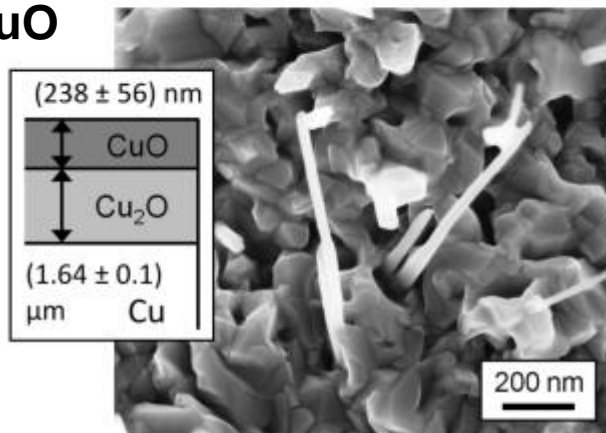
S. Mathews, M. Hans, F. Mücklich, M. Solioz, *Appl. Environ. Microbiol.* 79:8, 2605-11 (2013)

- oxidized model surfaces:

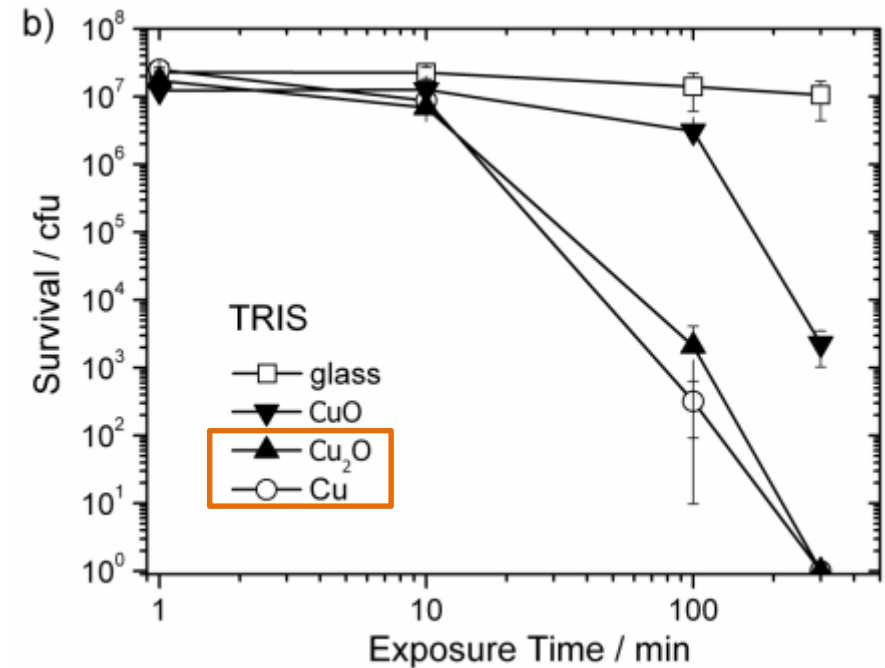
Cu₂O



CuO



- viability tests (similar for PBS)



- Cu₂O similarly high efficiency as Cu
- CuO → more passive

M. Hans, A. Erbe, S. Mathews, Y. Chen, M. Solioz, F. Mücklich *Langmuir* 29:52, 16160-6 (2013)

Vielen Dank für Ihre Aufmerksamkeit.

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Universität des Saarlandes

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Saarland (MECS)**

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Wir freuen uns auf Ihren Besuch!

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Uni des Saarlandes
Grundlagen

Material Engineering Center
Saarland
Steinbeis Forschungszentrum
Industriekooperationen



Internationalität
Flavio Soldera



Elektr.Kontakte
Kim Trinh



Kupfer
Michael Hans



Laborleiter
Christoph Pauly



Aluminium
Michael Engstler



Oberflächen
Carsten Gachot



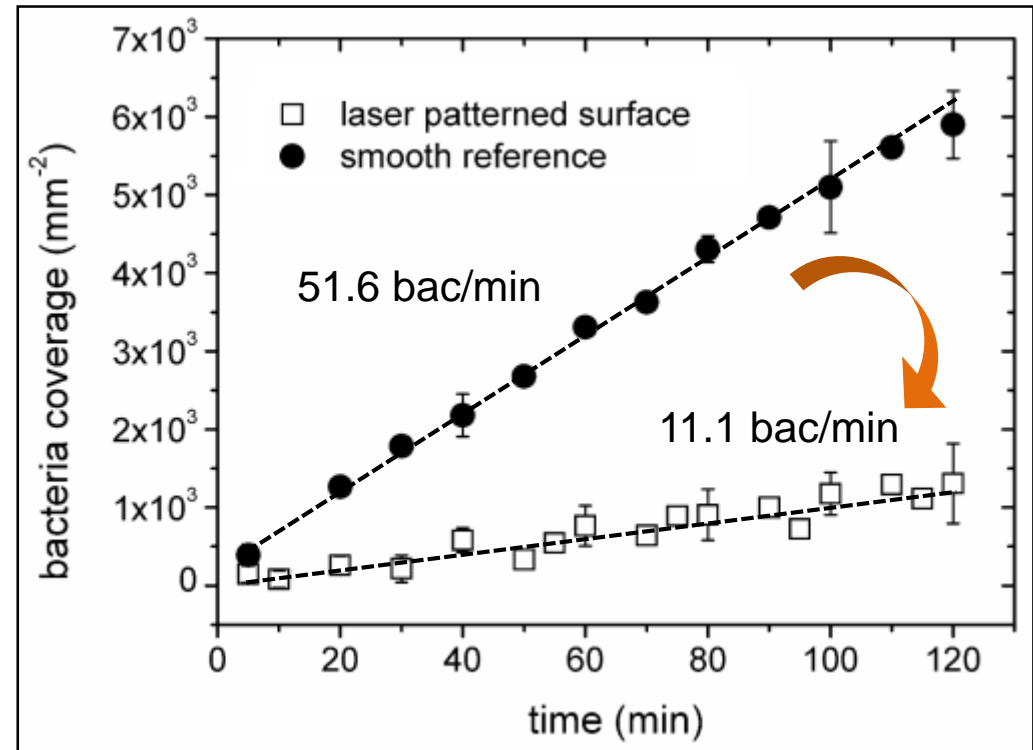
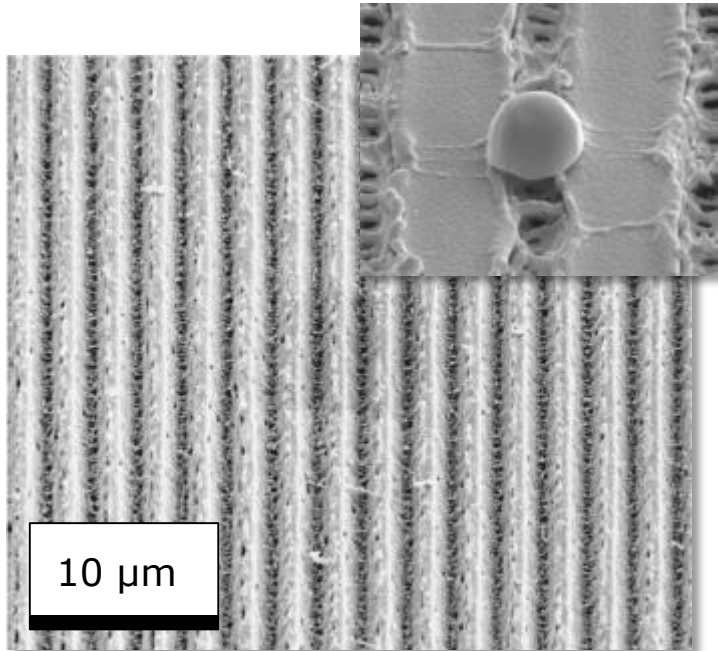
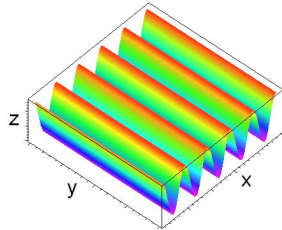
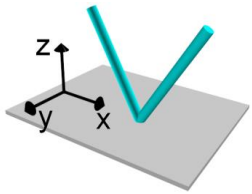
Stahl
Dominik Britz



Tomographie
Jeni Barrirero

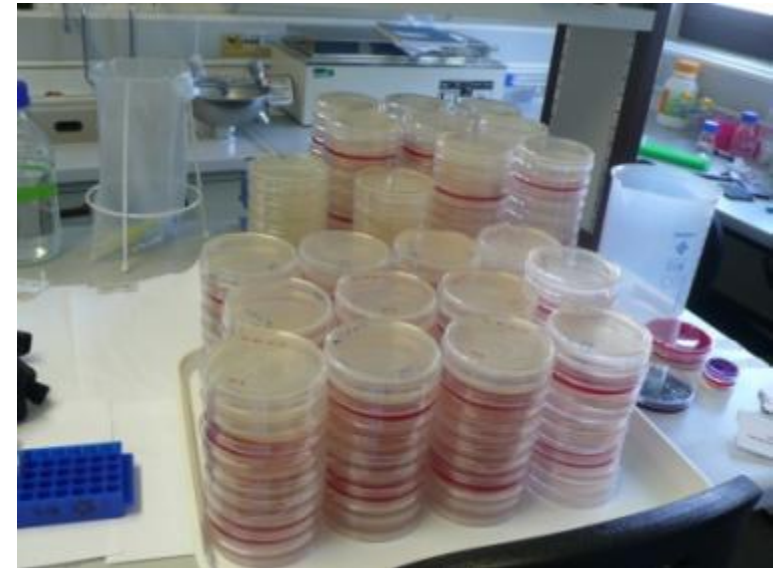
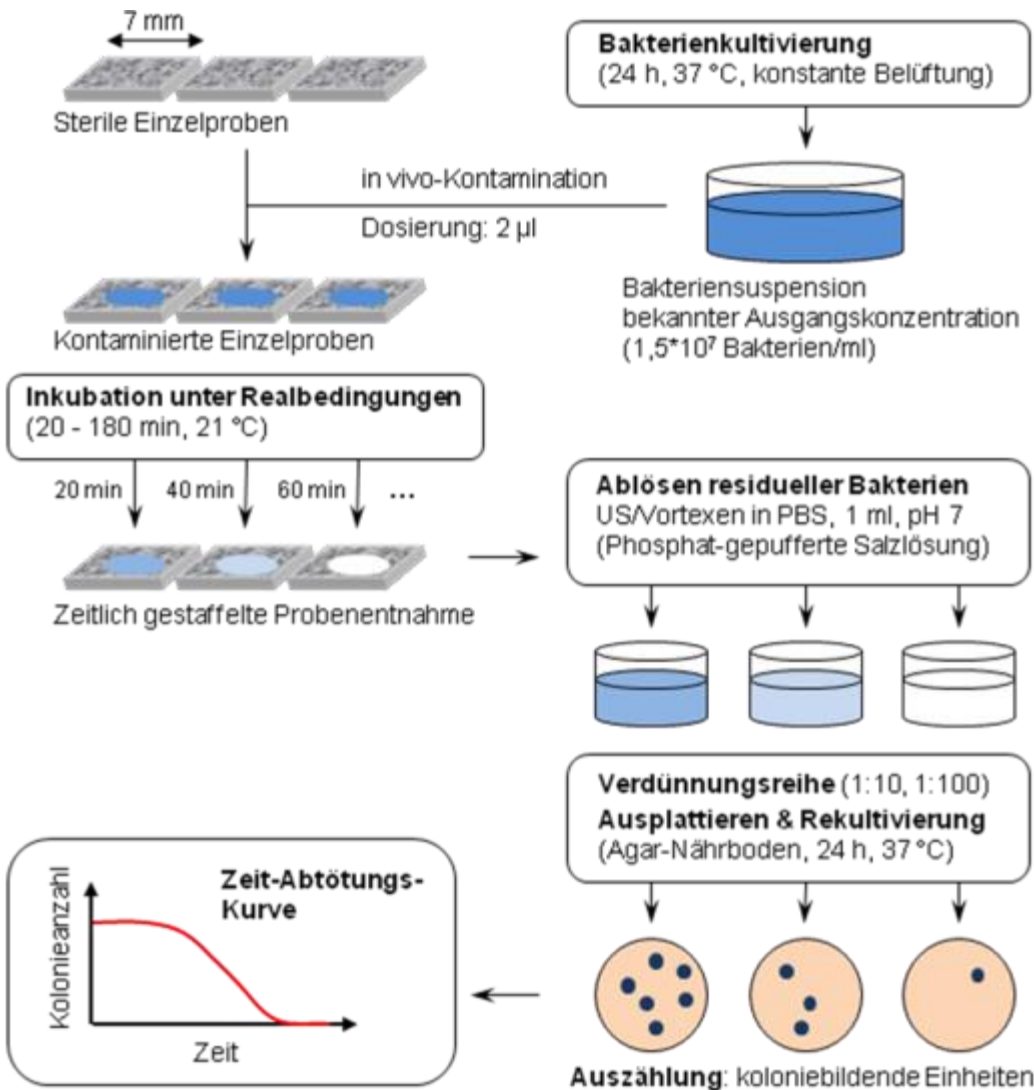
Maßschneidern der Kontakteigenschaften?

→ Adhäsion der Bakterien



bacterial adhesion control through topography?

→ ongoing research...



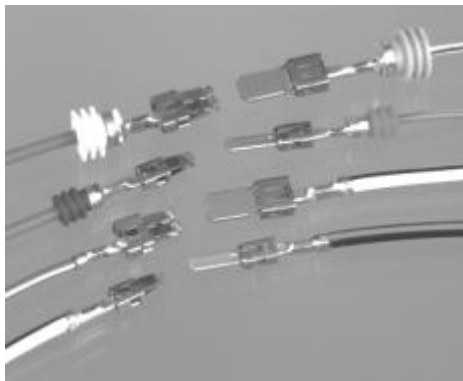
statistische Auswertung

Purpose of connectors:

- Creation of a **separable electrical connection** between two systems

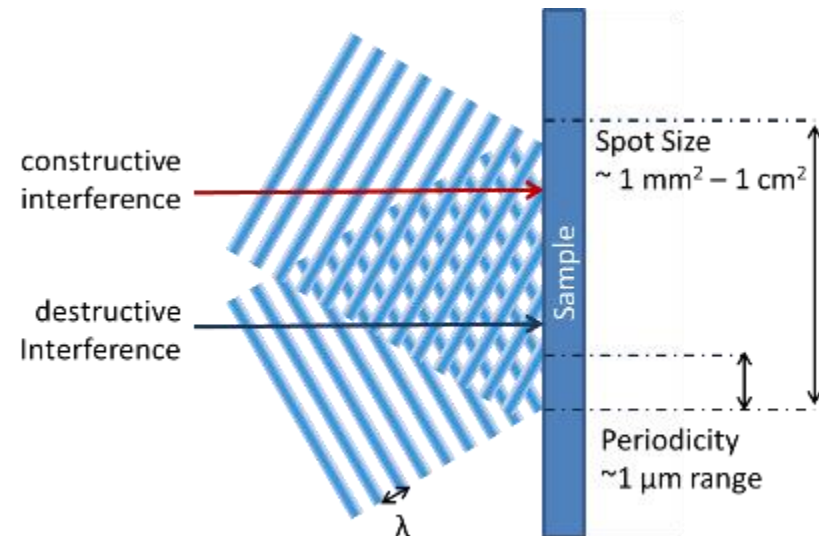
Main requirements on this electromechanical system:

- Low and constant contact resistance
- High wear resistance
- Low and stable insertion-/withdrawal forces



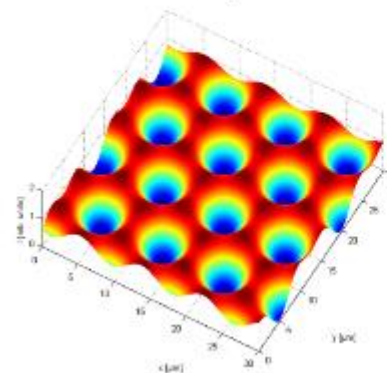
Flat contact systems for automotive applications
[www.te.com]

Laser Interference Principle:

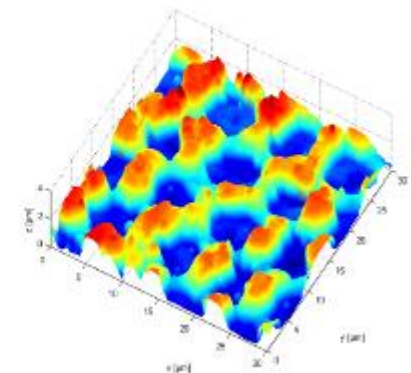


3 beam laser interference

Calculated intensity distribution



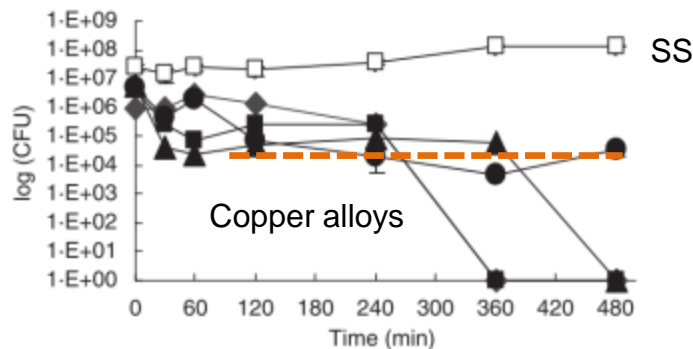
real surface from AFM measurement



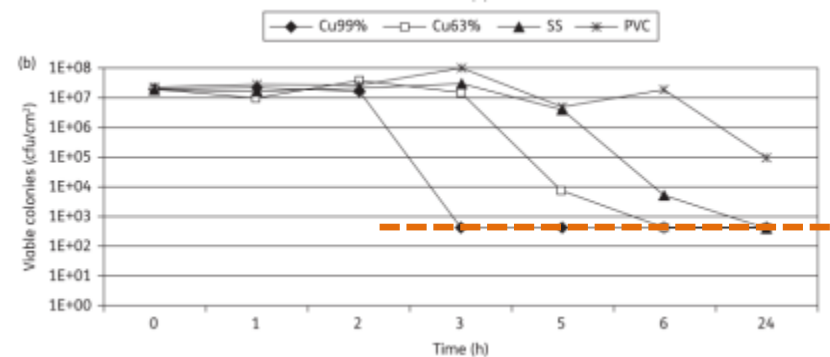
- buffer environment favors formation of less effective CuO

→ (false) self inhibitory effect due to **CuO**-formation?

“plateau-phase” in literature



J. Elguindi et al. *J. Appl. Microbiol.* 106:5 1448-55 (2013)



M. Souli et al. *J. Antimic. Chemother.* 68:4 852-7 (2013)