Laser-assisted generation of tribological surfaces

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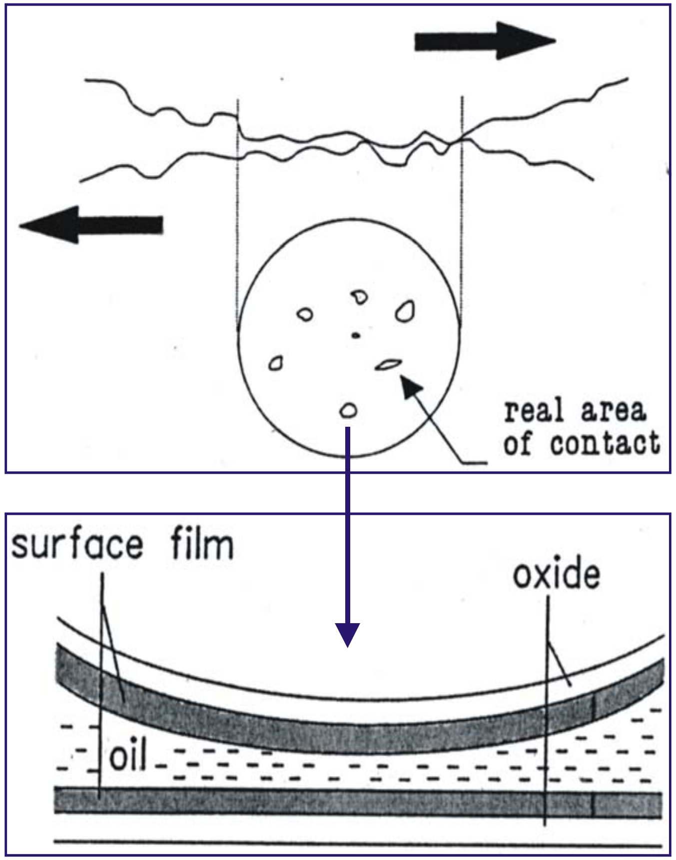
Contents

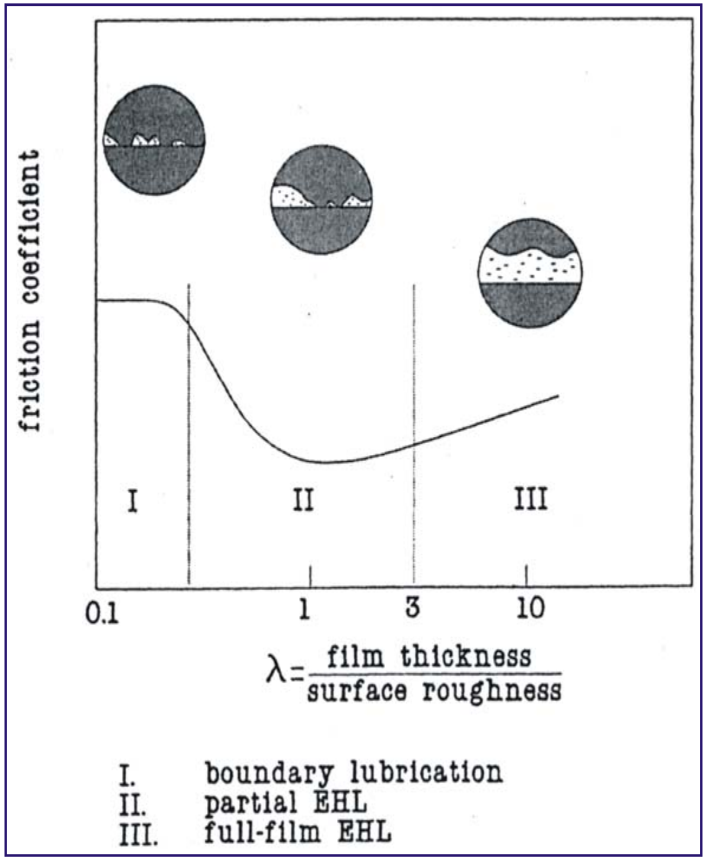
- Introduction: friction, wear, surface structures
- Fundamentals on laser texturing
- Tests on laser-engineered tribological surfaces
- Laser-engineered tribological surfaces: various application fields
- Case study
- Conclusions

Friction between two hard surfaces

Gliding: macro- and microcontacts

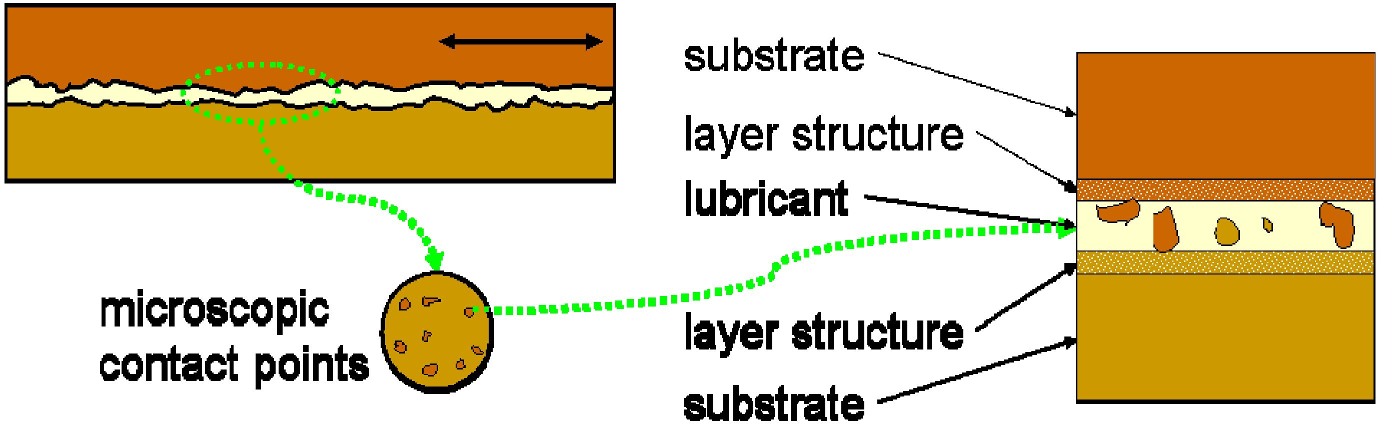


Friction domains, Stribeck curve:



Gliding surfaces

- **Morphology**



- **Parameters**
  - temperature
  - gliding speed
  - chemical reactions
  - pressure
  - surface morphology

- **Wear**
  - contaminants
  - debris particles

Microstructuring?

- **Prevention of abrasive wear**

- hard, protective coatings
- additives

- control of viscosity
- circulated, filtered lubricant

- proper choice of hardness (1:3 ratio)
- changes in the substrate geometry

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Interactions (I)

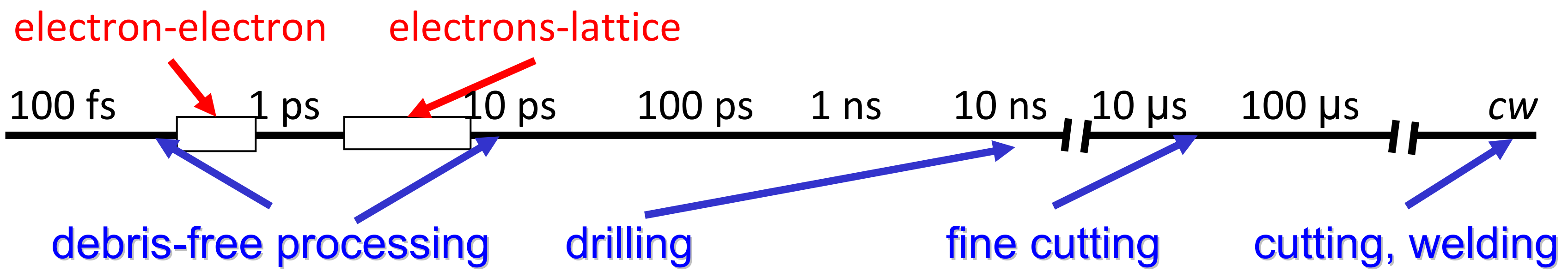
Laser energy coupling

- focussed laser beam: **E** field
- electron gas excitation
- accelerated free electrons

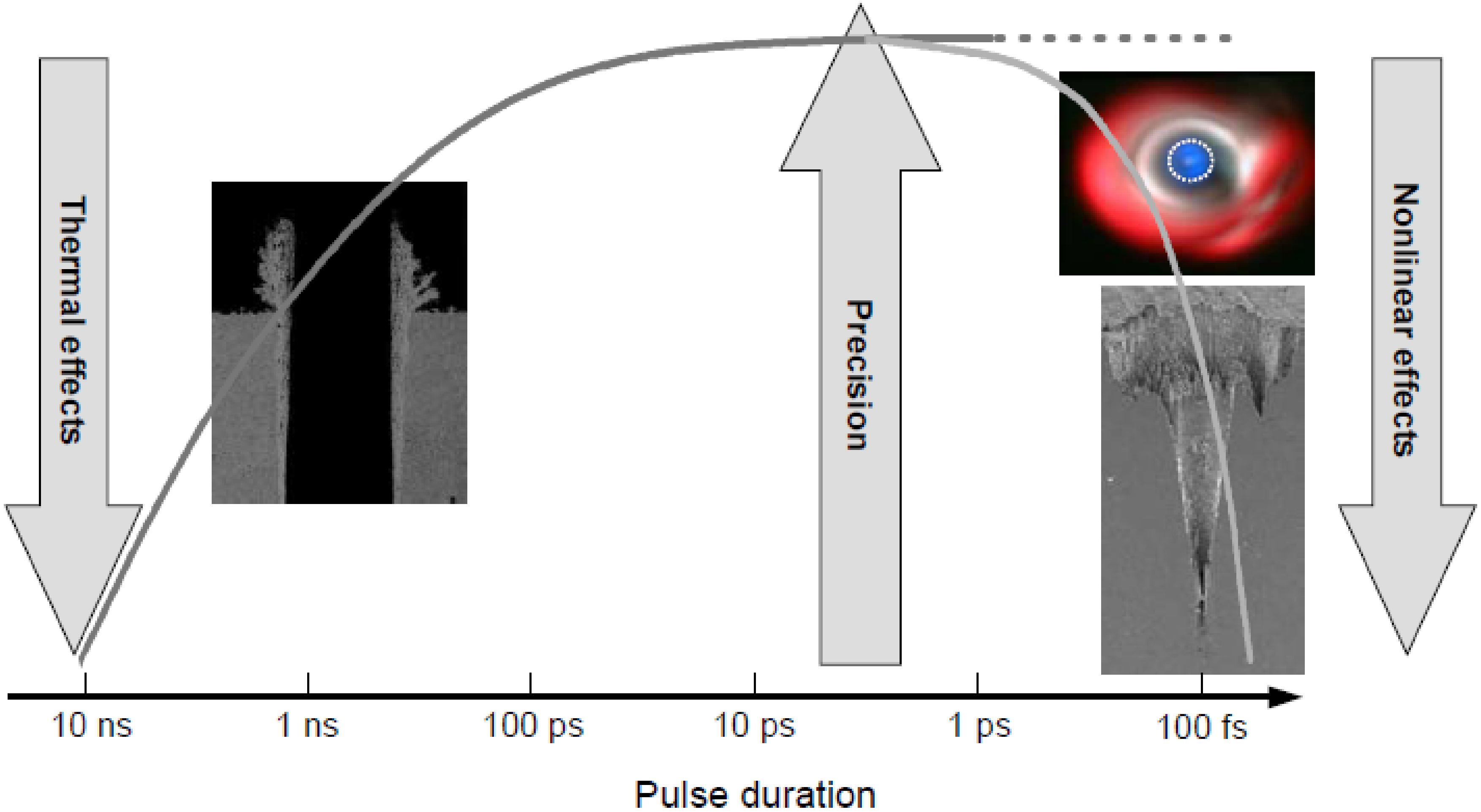
Energy transfer sequence

- electron-electron collisions
- electron-lattice interactions
- thermalization of incident energy
- heat flow

Specific interaction times

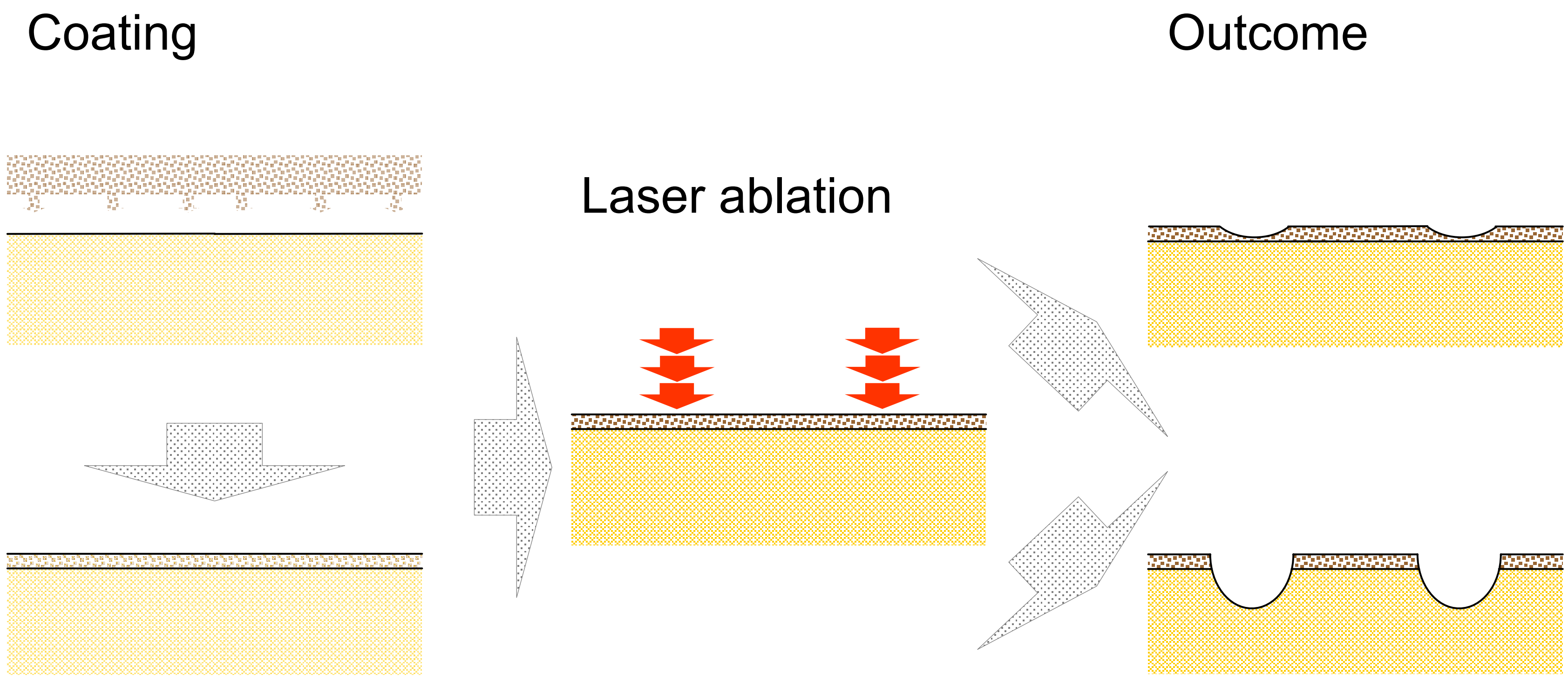


Interactions (II)

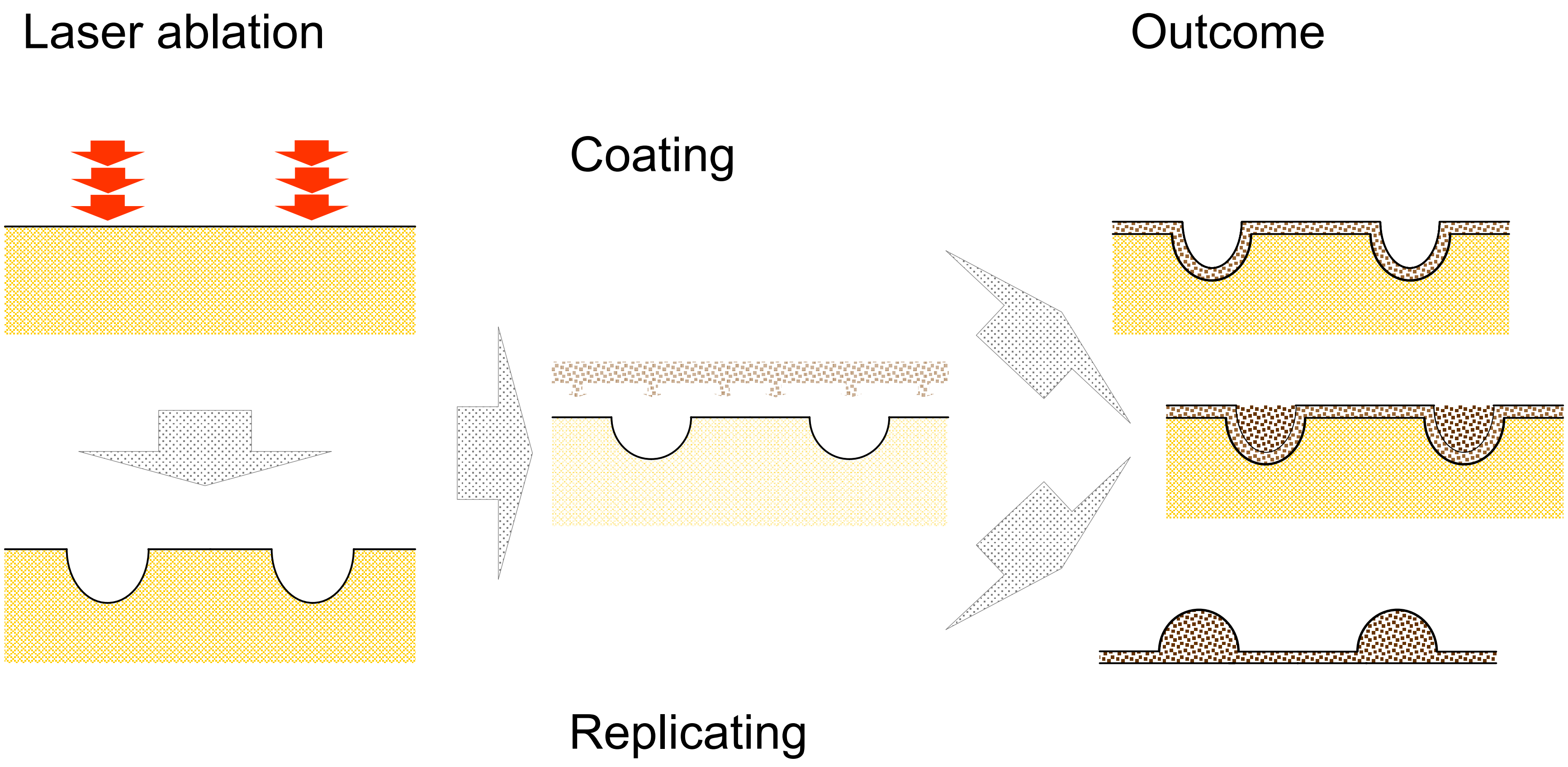


Proc. SPIE 5339 (2004)

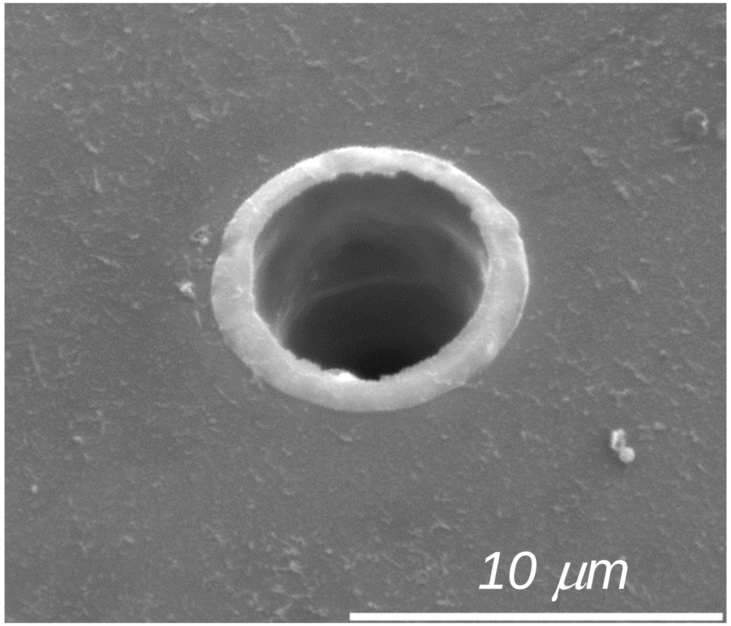
Laser patterning: direct processing

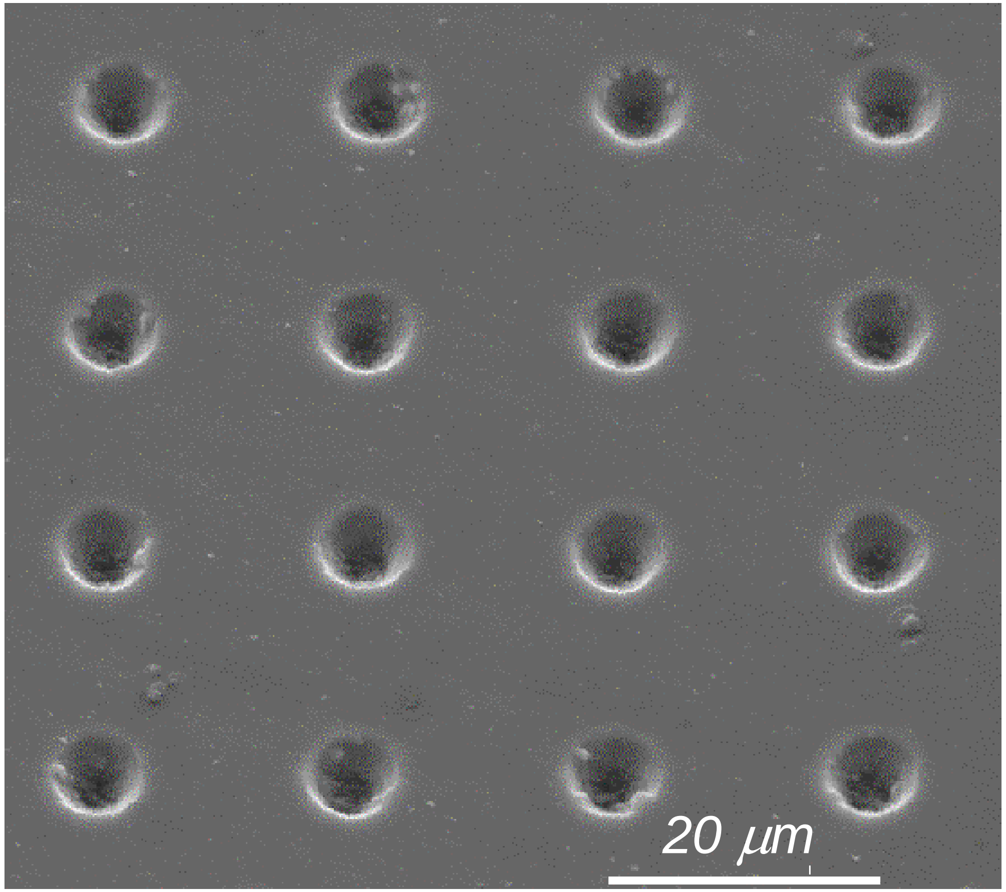


Laser patterning: indirect processing



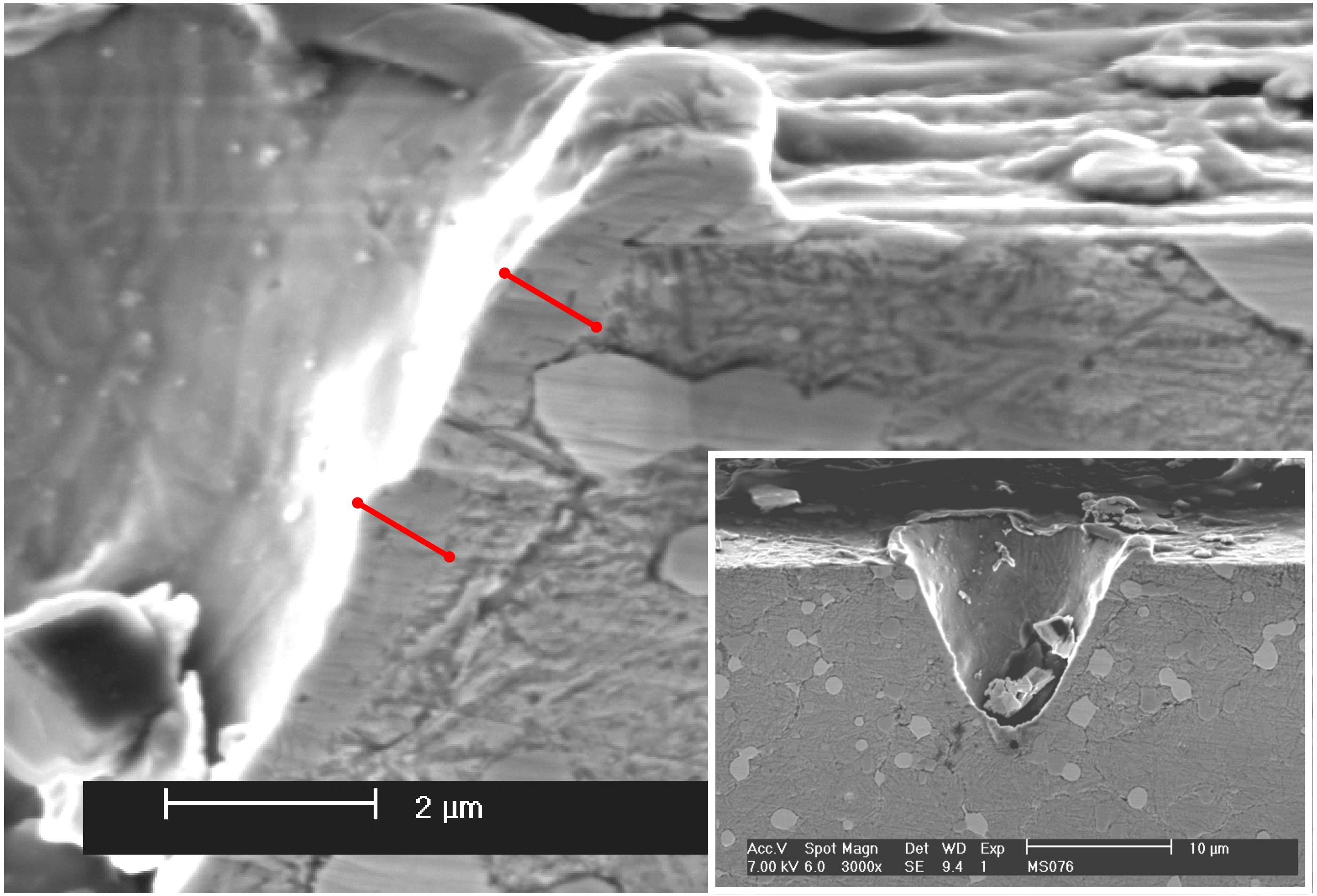
Laser-ablated pores in stainless steel





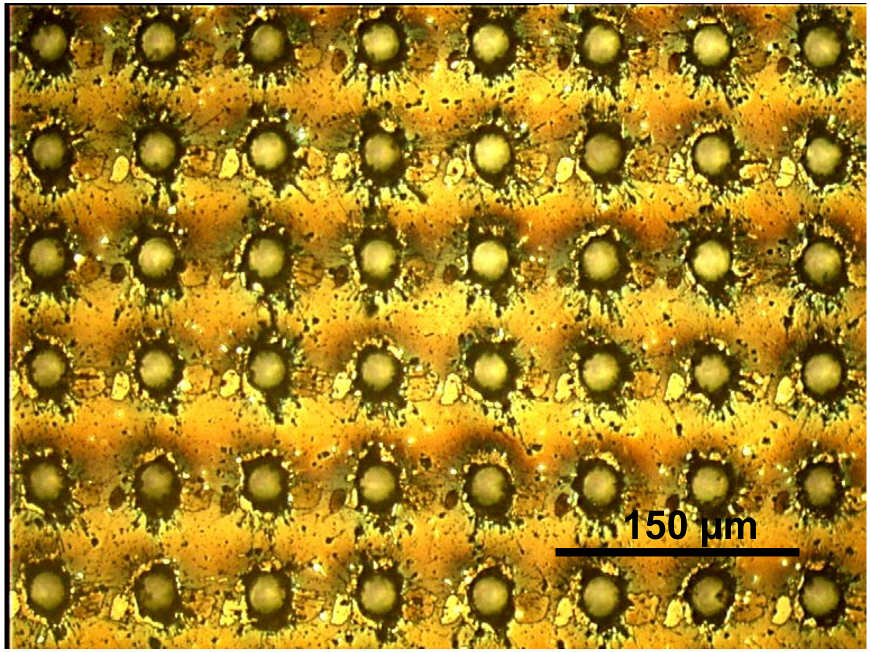
Cross-section (etched)

- alloyed steel
- < 1 µm layer
- increased hardness

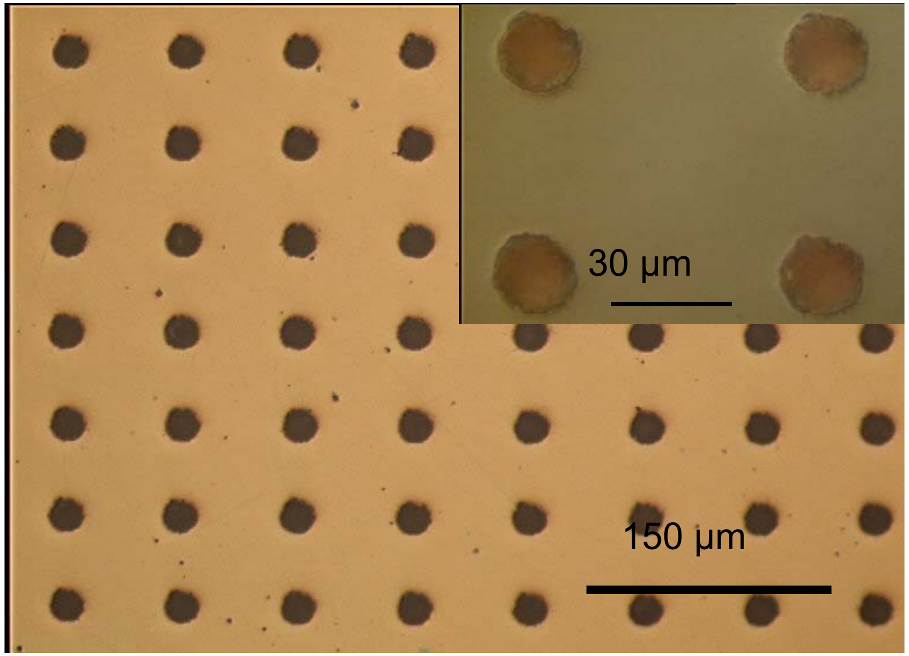


Indirect processing: DLC on 52100 Steel

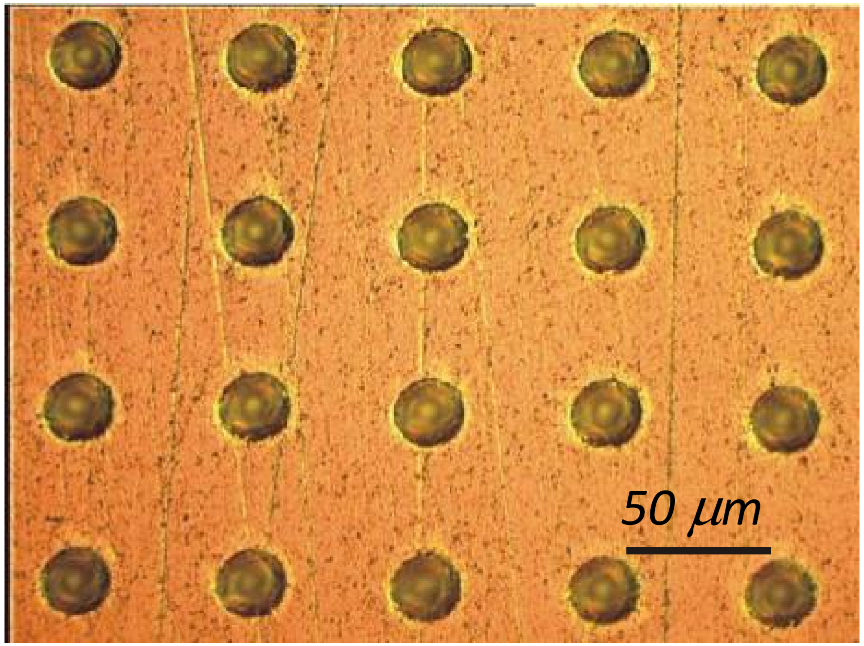
Laser patterned, polished, DLC coated surface:
general view and detail

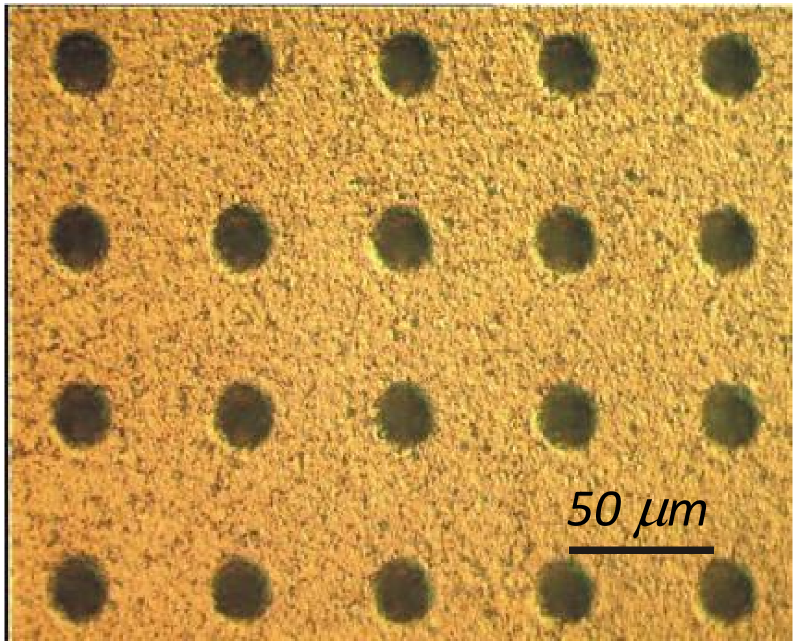


Laser patterned steel surface (not polished)



Indirect processing: TiCN on WC-Co



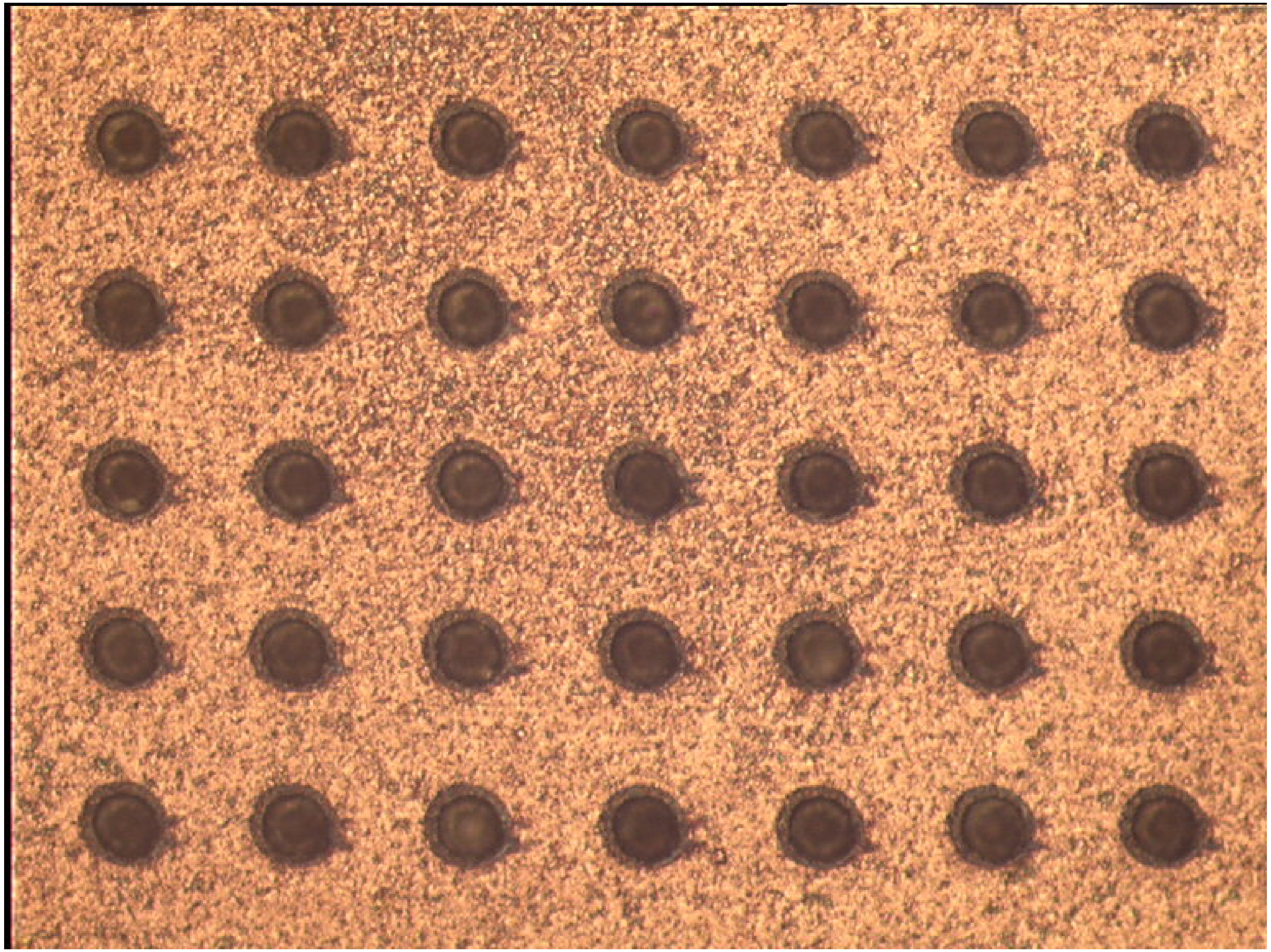


Structuring:
- WC-10 Co
- 6 pulses
- 30-40 µJ

Postprocessing:
- gentle polishing
- short cleaning

Coating:
- CVD
- Ti(C,N)
- thickness: 3-4 µm

Direct processing, fs pulses (I)



Film:

TiCN

Substrate:

WC – 10 Co

Pulses:

100 / pore

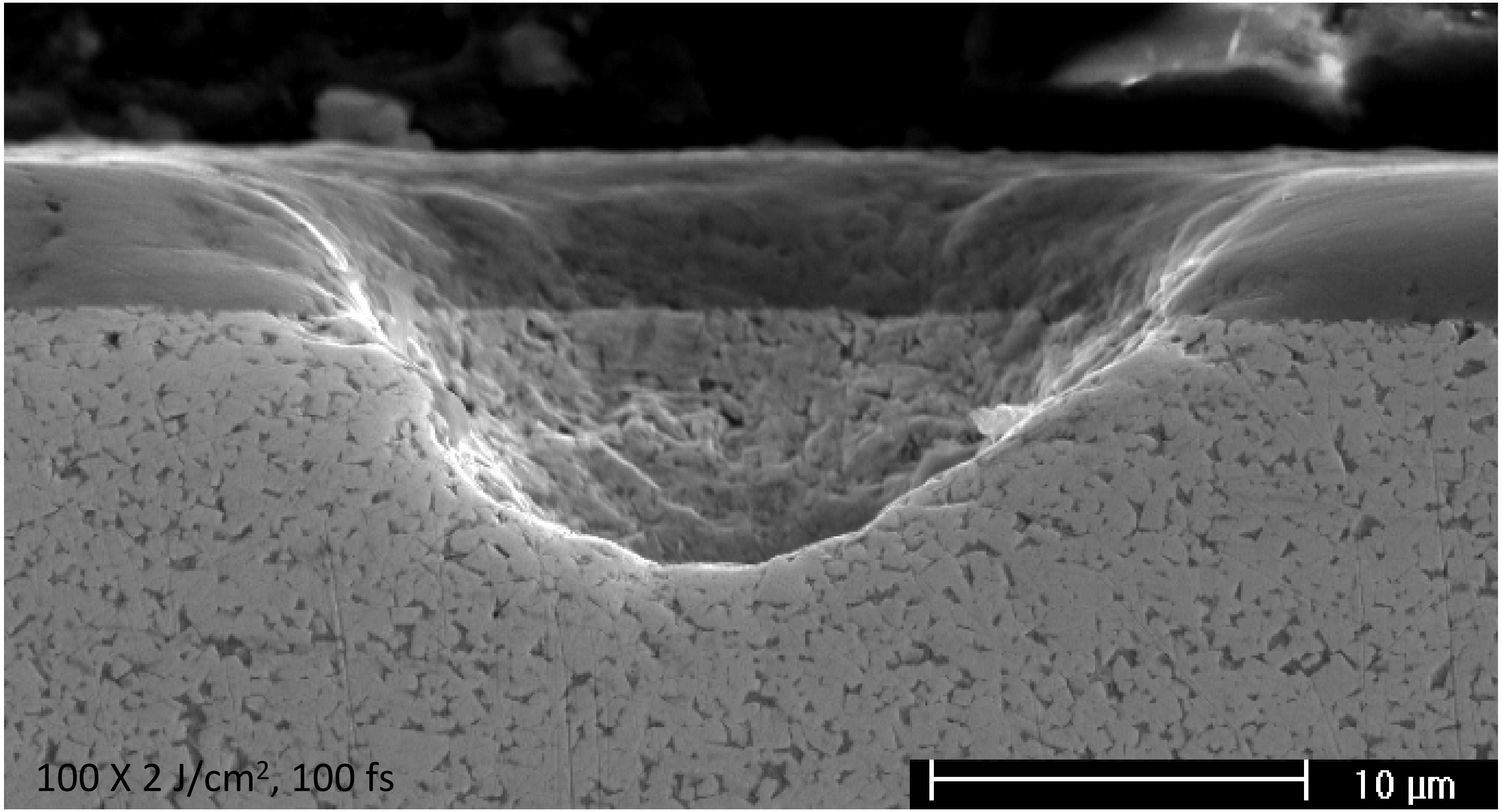
Pulse duration:

100 fs

Fluence:

2 J/cm^2

Direct processing, fs pulses (II)



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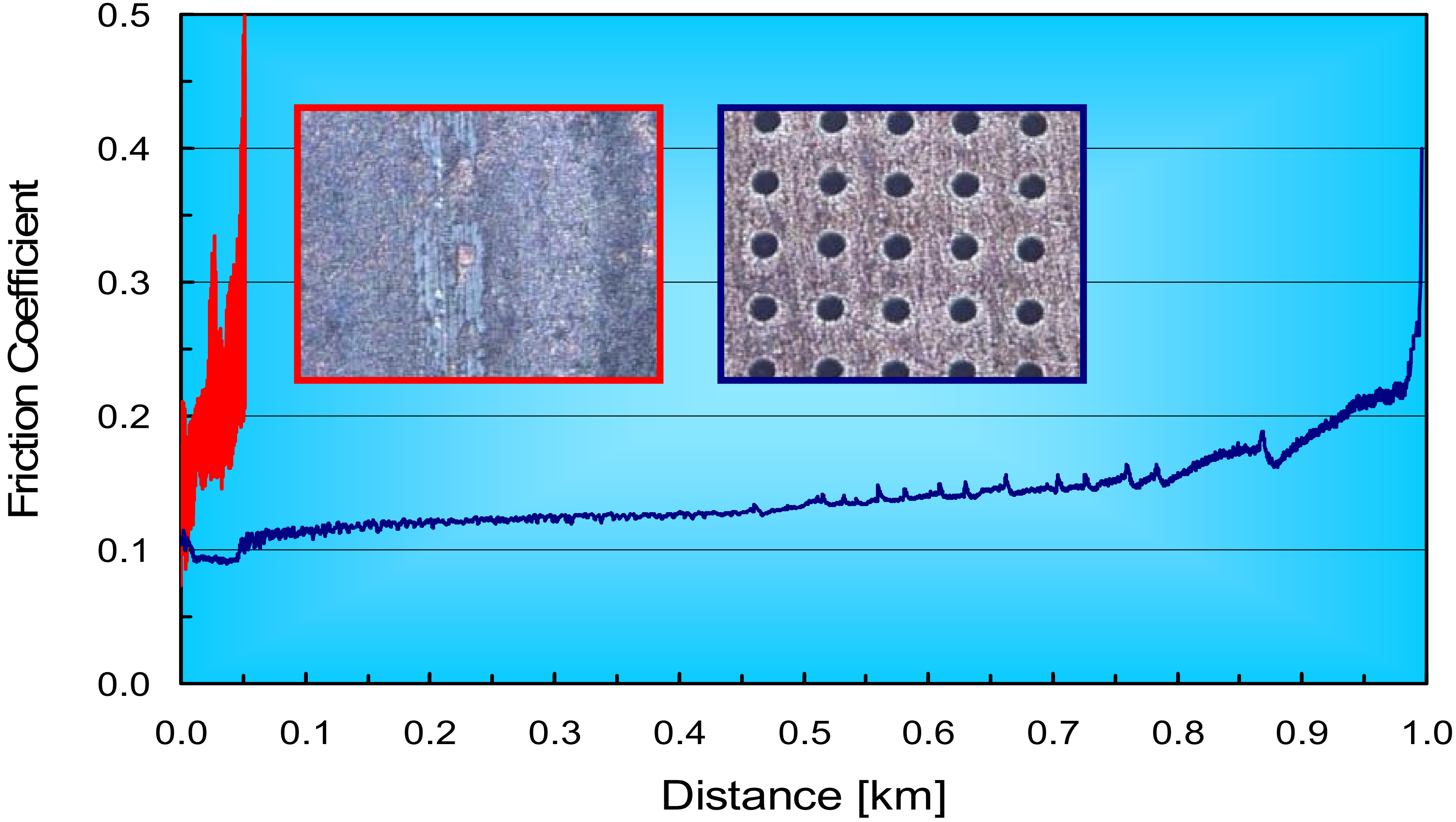
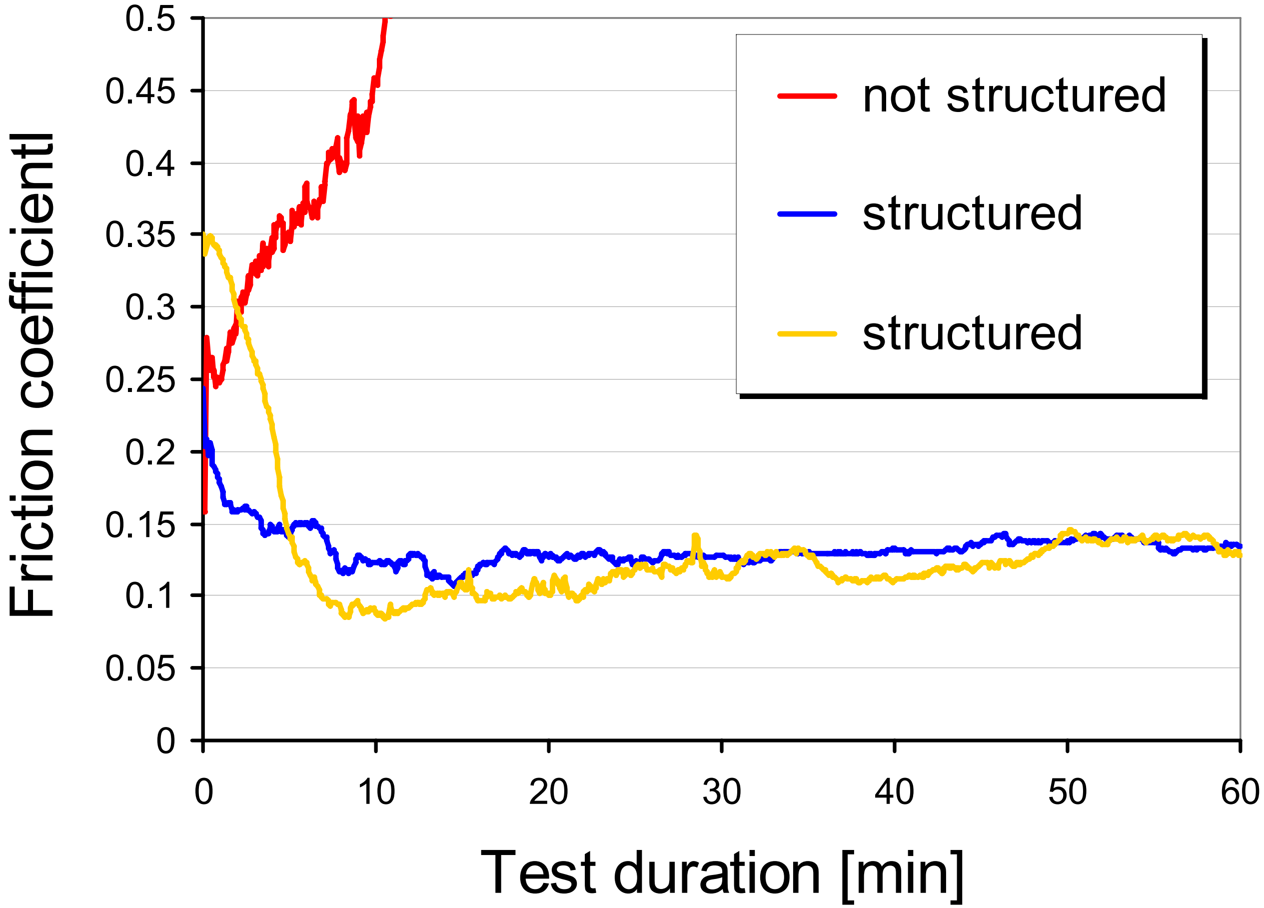
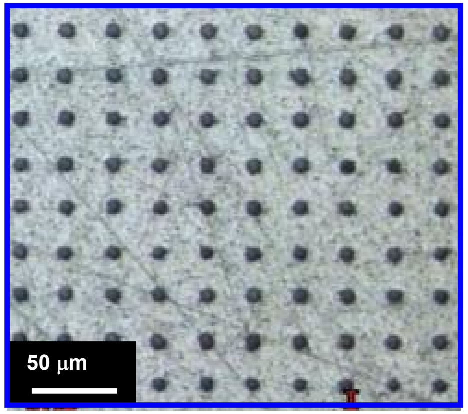
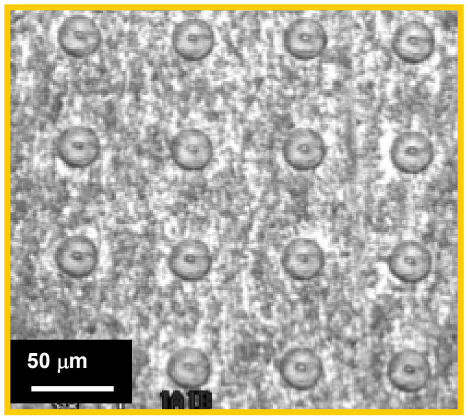
Tribo-tests: laser-patterned & coated surface



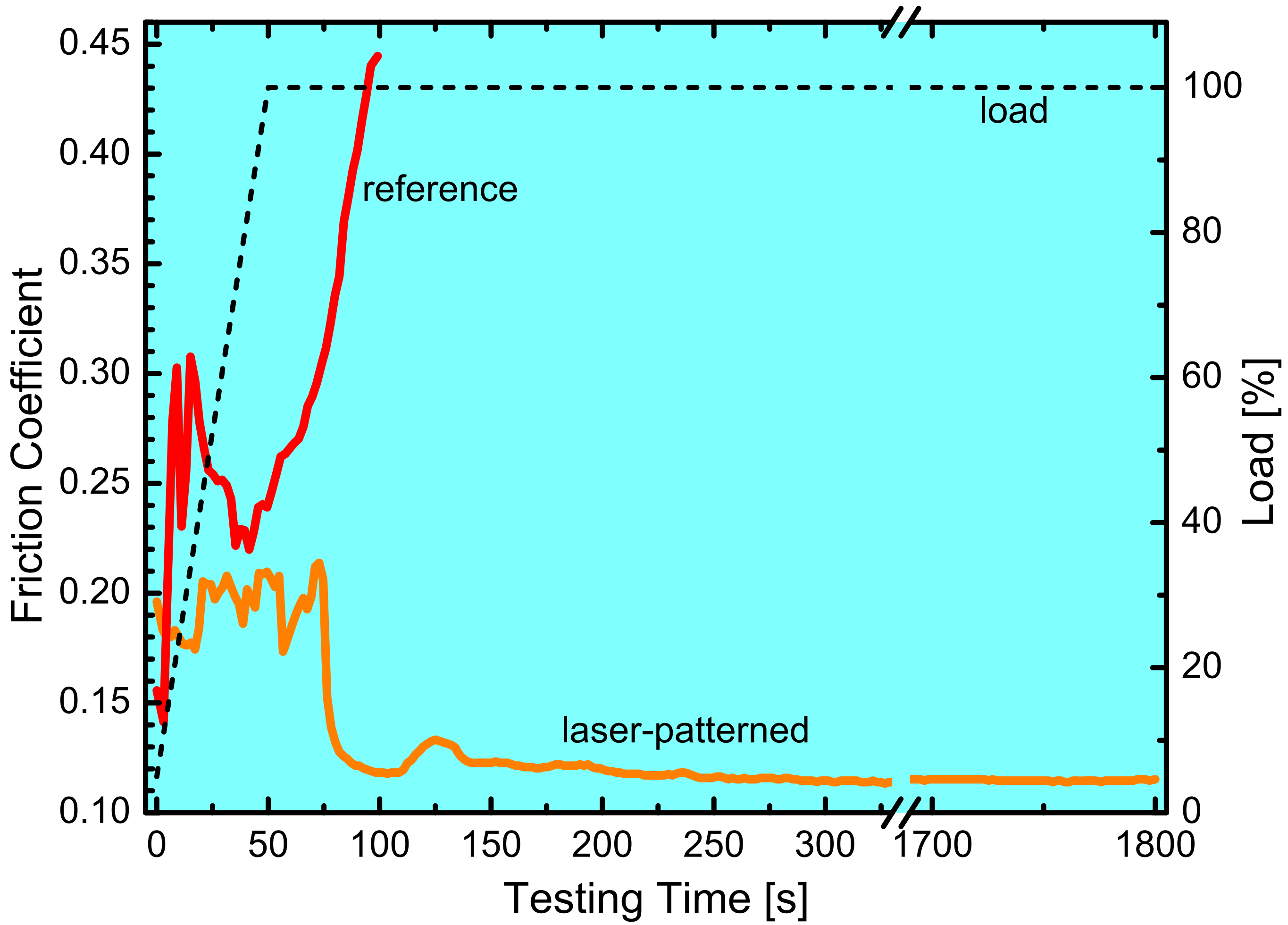
Lifetime increasing through laser patterning (uncoated)







Lifetime increasing through laser patterning (coated)



Load:

50 N – 1000 N

Rise Time:

30 s

Pressure:

250 N/mm²

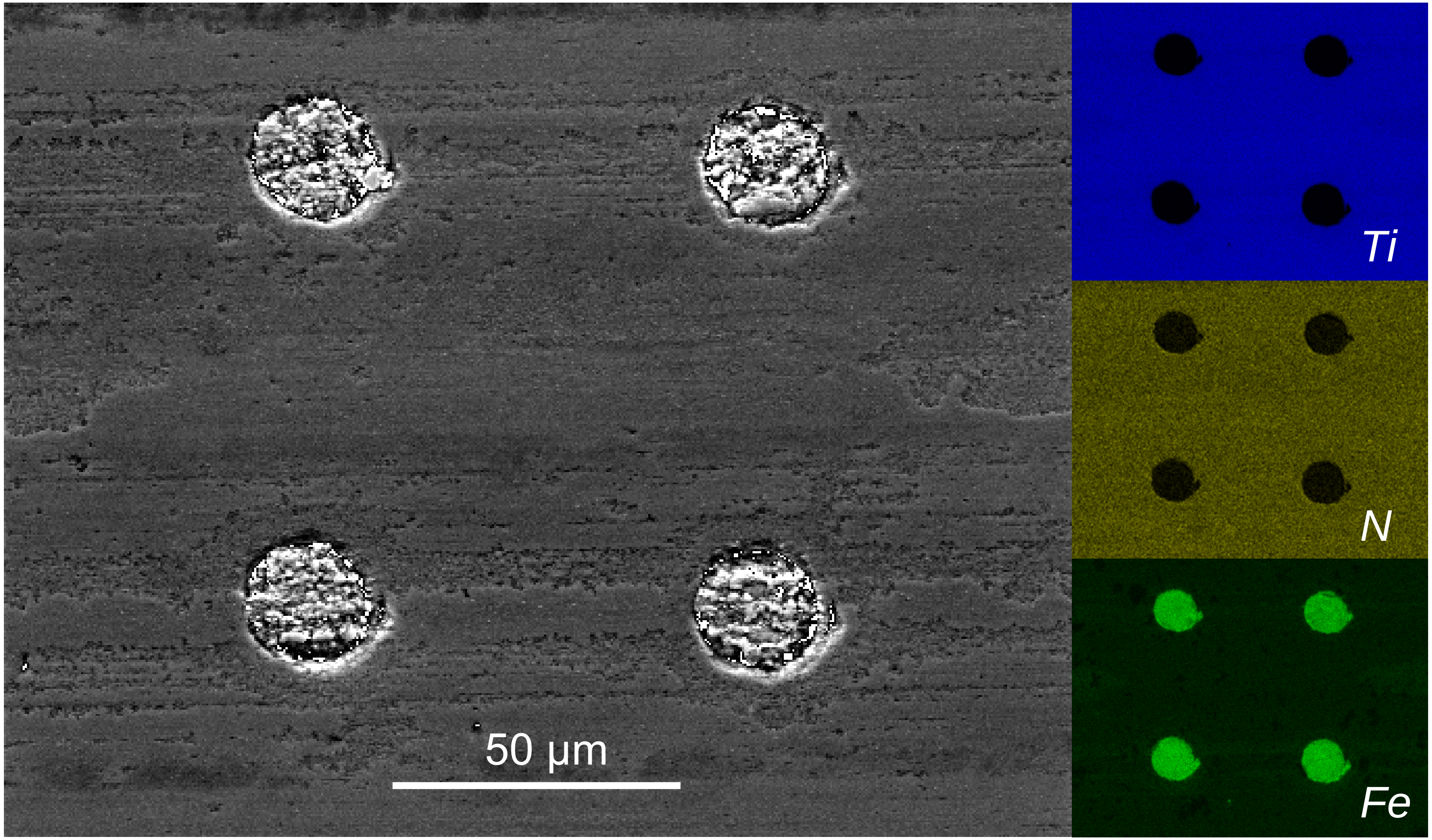
Stroke:

2 mm

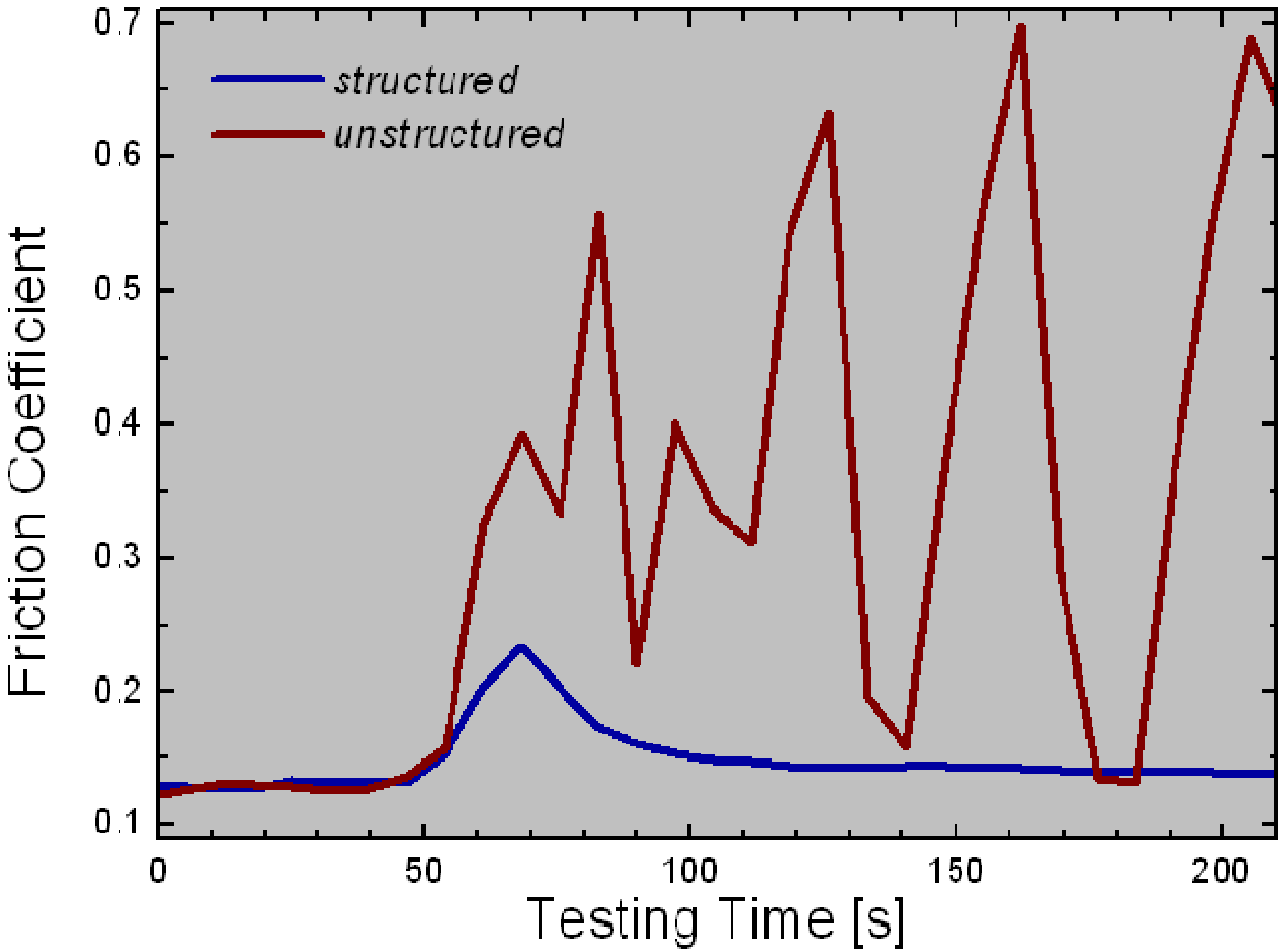
Frequency:

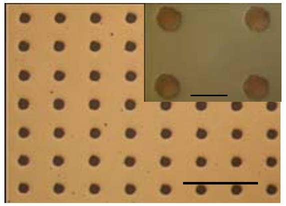
10 Hz

Surface after tribo-tests



Tribological tests, DLC, indirect patterning





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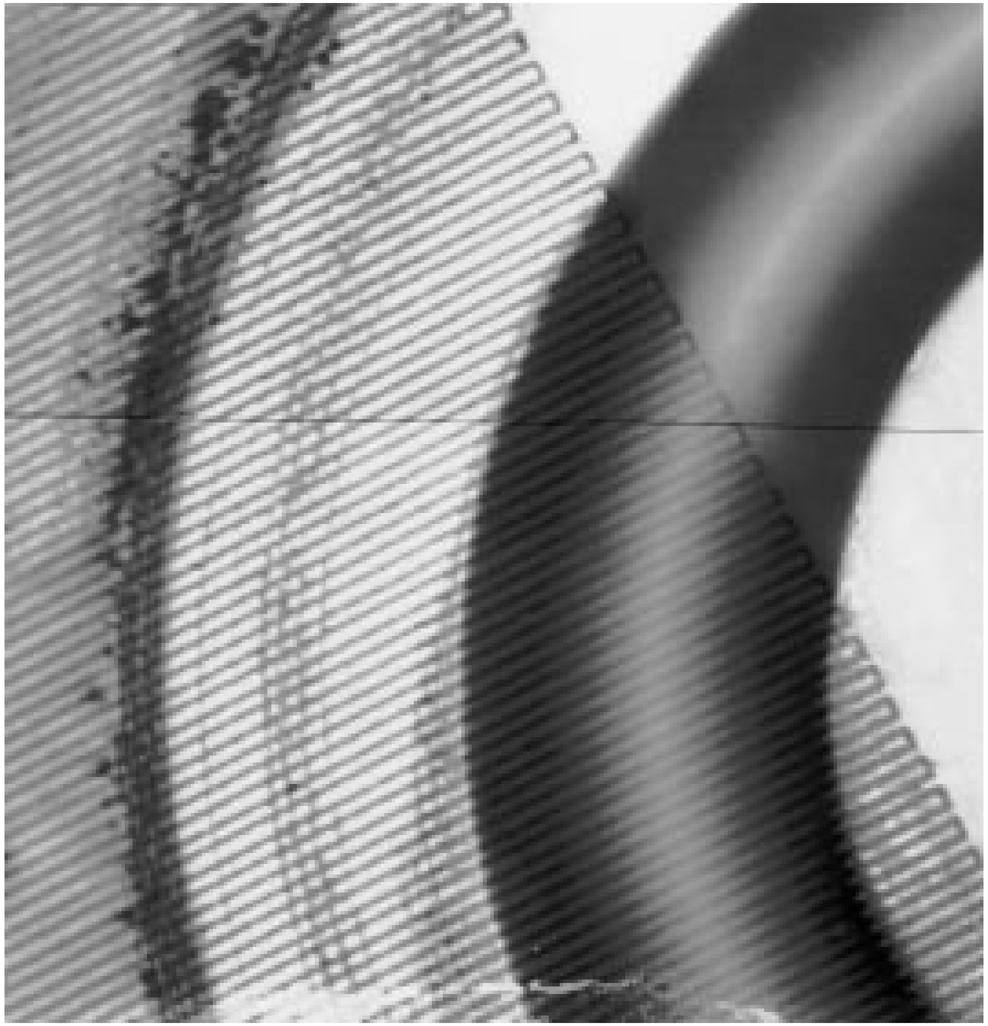
Microasperity Lubrication

- photoengraving process
- etching of smooth-lapped stators

„Furthermore, from the load support observed, it is apparent that the use planned microasperities is an effective method for lubricating the parallel surfaces of face seals and thrust-bearing surfaces."

Journal of Lubrication Technology (1968) 351

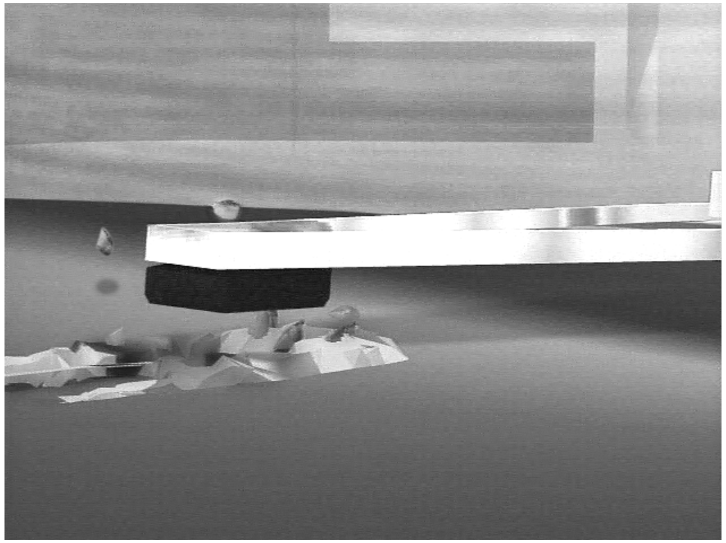
Lubricated friction of laser micro-patterned sapphire flats



- crucial effect on the endurance of lubricated sliding
- sufficiently fine grooves might lead to steady-state conditions with virtually no wear and seemingly unlimited sliding
- **Each particular application requires its own optimization.**

Tribology Letters 4 (1998) 237–241

Protective head parking



- precisely placed landing area,
  with controlled roughness

- smooth data area,
  where high density data is written.

- landing area: laser-produced bumps
  - of uniform size and height
  - with defined patterns
  - to minimize wear and friction due to repeated head landing

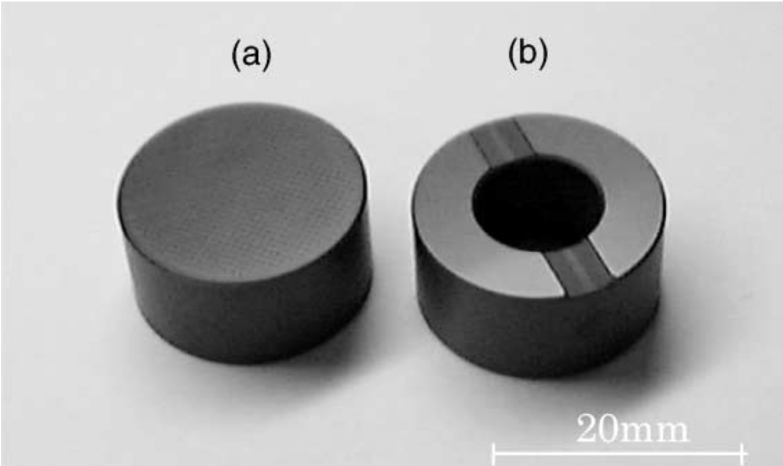
- *e.g.*, Ni–P-plated Al–Mg substrates

- molten pool, instantaneous solidification
  → discrete topographical features

Wear 230 (1999) 11-23

gd1

Laser surface texturing for hydrodynamic lubrication

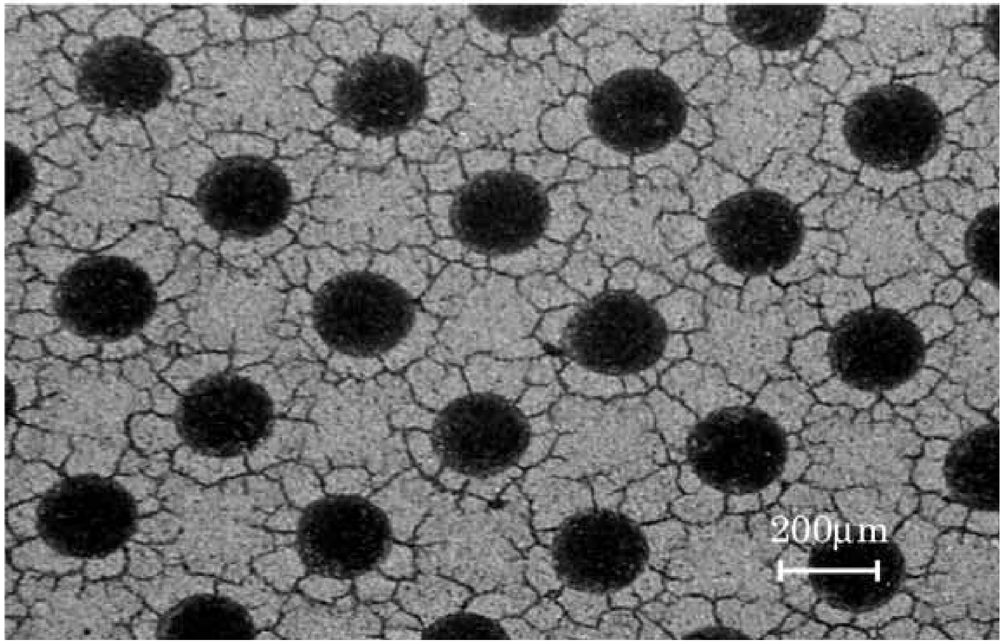


● SiC cylinder sliding on a SiC disk

● in water

● increase of critical load: 20%

● effect maintained between 400 and 1200 rpm

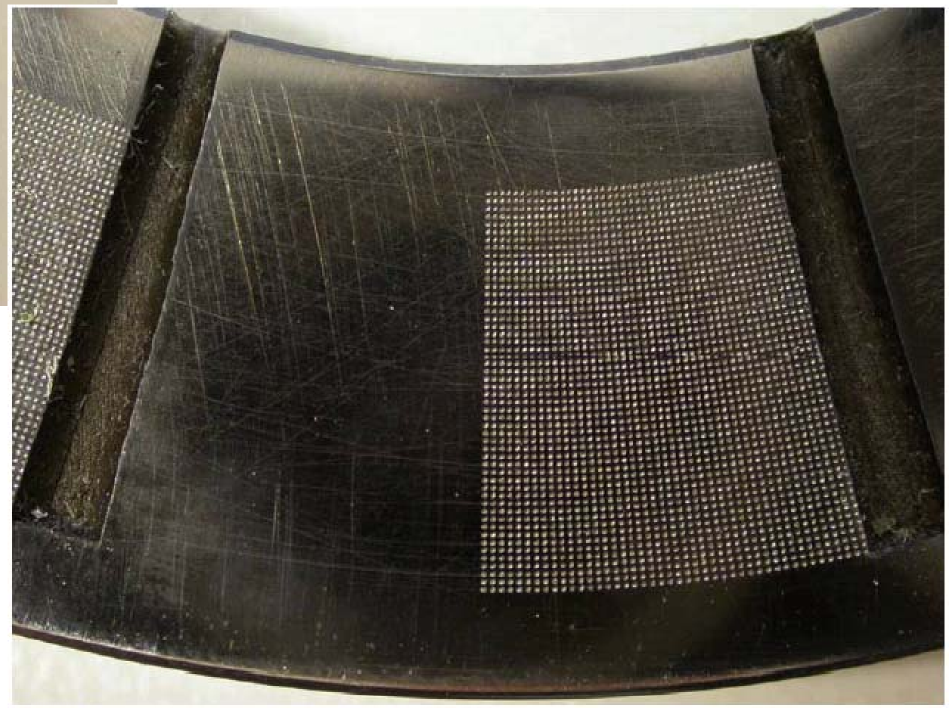


Tribology International 34 (2001), 703–711

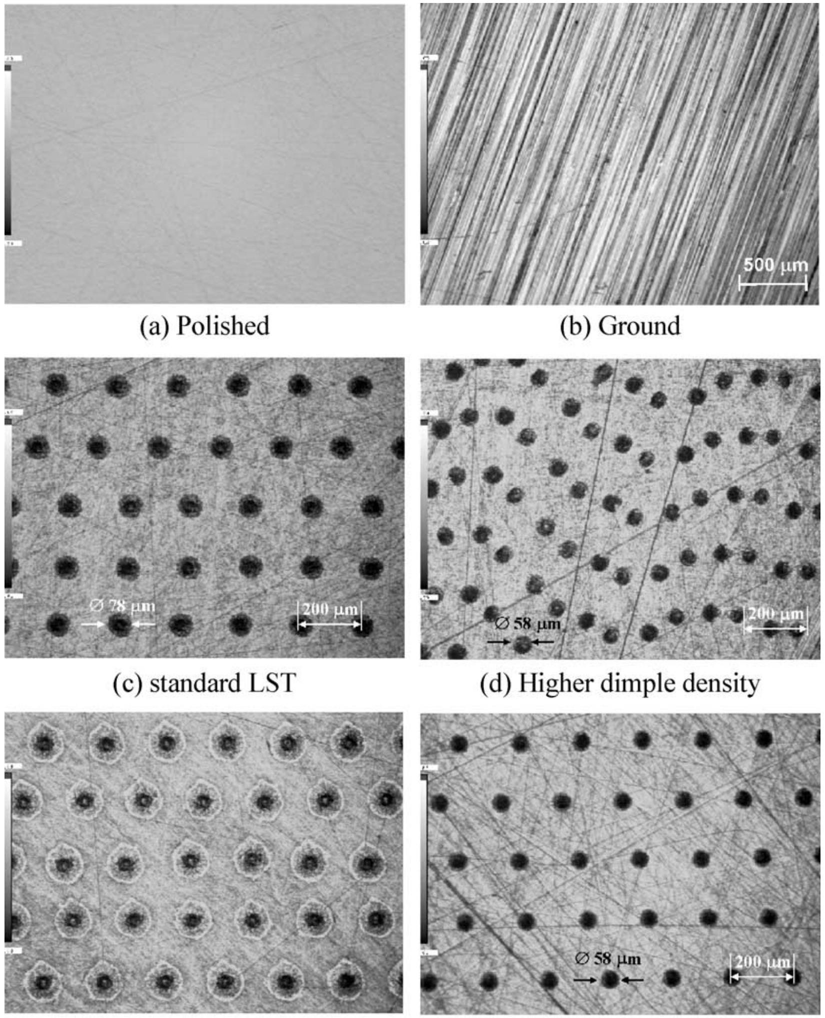
gd1 Mechanical seals are used for the sealing of rotating shafts against a stationary housing, e.g. in pumps and agitators. The stationary" part of the seal is usually located at the housing, the rotating" part is fixed on the shaft. The high-precision face-machined sliding faces rotate axially in opposition. The sliding faces are pressed against each other by means of spring force, thus preventing the opening of the seal at stand-still. The seal faces are statically sealed against the housing and the shaft by secondary seals (O-rings). With the entry of the pumped medium into the minimal sealing gap a lubricating film is generated and the sealing effect is thus obtained.

Gabriel Dumitru; 18.03.2009

Laser surface texturing for bearing rings



Laser texturing of seals: transitions in lubrication regime

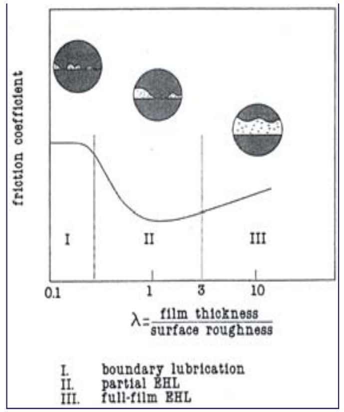


(a) Polished (b) Ground

(c) standard LST (d) Higher dimple density

(e) standard without lapping (d) Lower dimple density

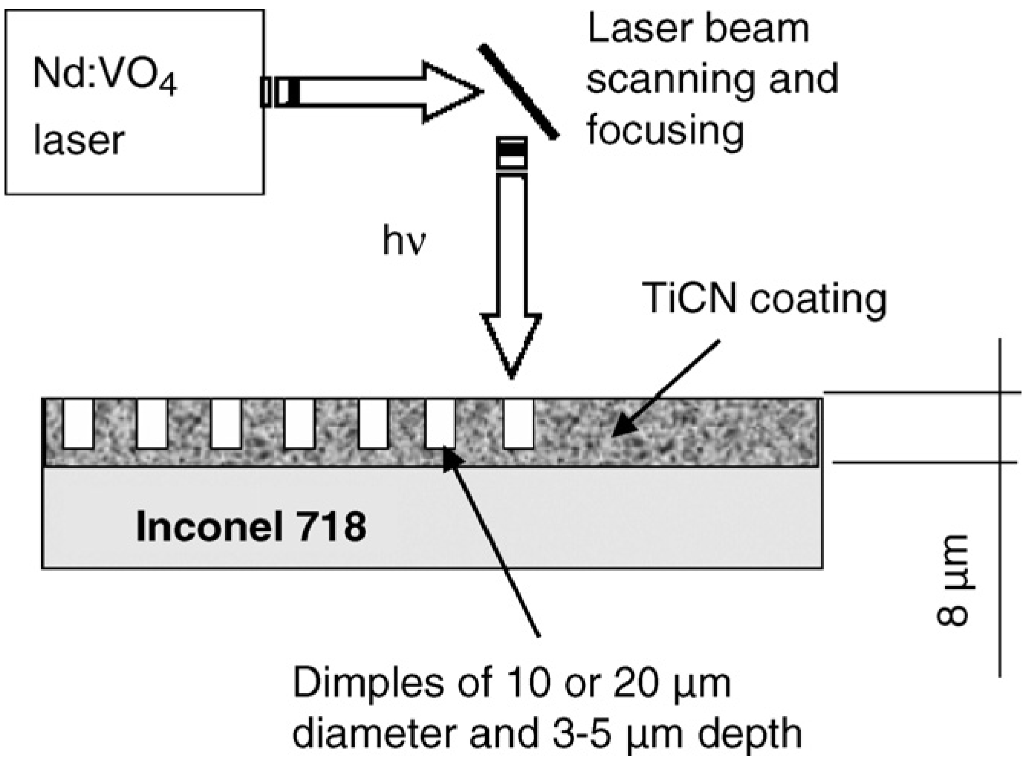
- expand the range of the hydrodynamic lubrication regime
- reduce the friction coefficient under similar operating conditions
- reduce friction in oil-lubricated tribological under a boundary lubrication regime



Tribology International 38 (2005) 219–225

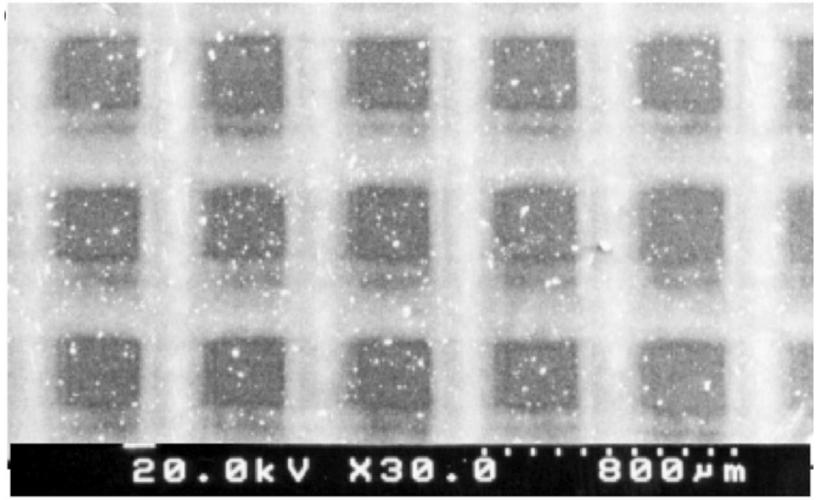
Laser surface texturing for adaptive solid lubrication

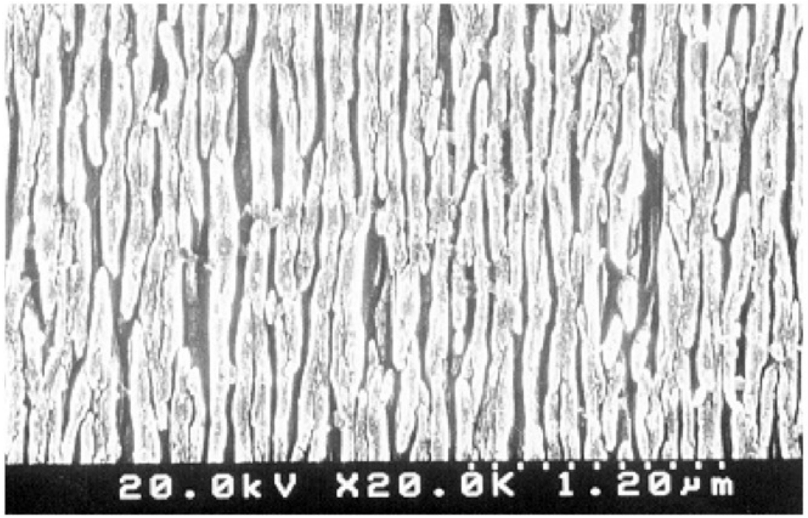
- micrometer sized reservoirs on hard TiCN coatings
- solid lubricants, *e.g.* based on MoS_2 and graphite
- lifetime increase: 10 X



Wear 261 (2006) 1285–1292

Laser-induced nanostructuring (fs) on DLC films

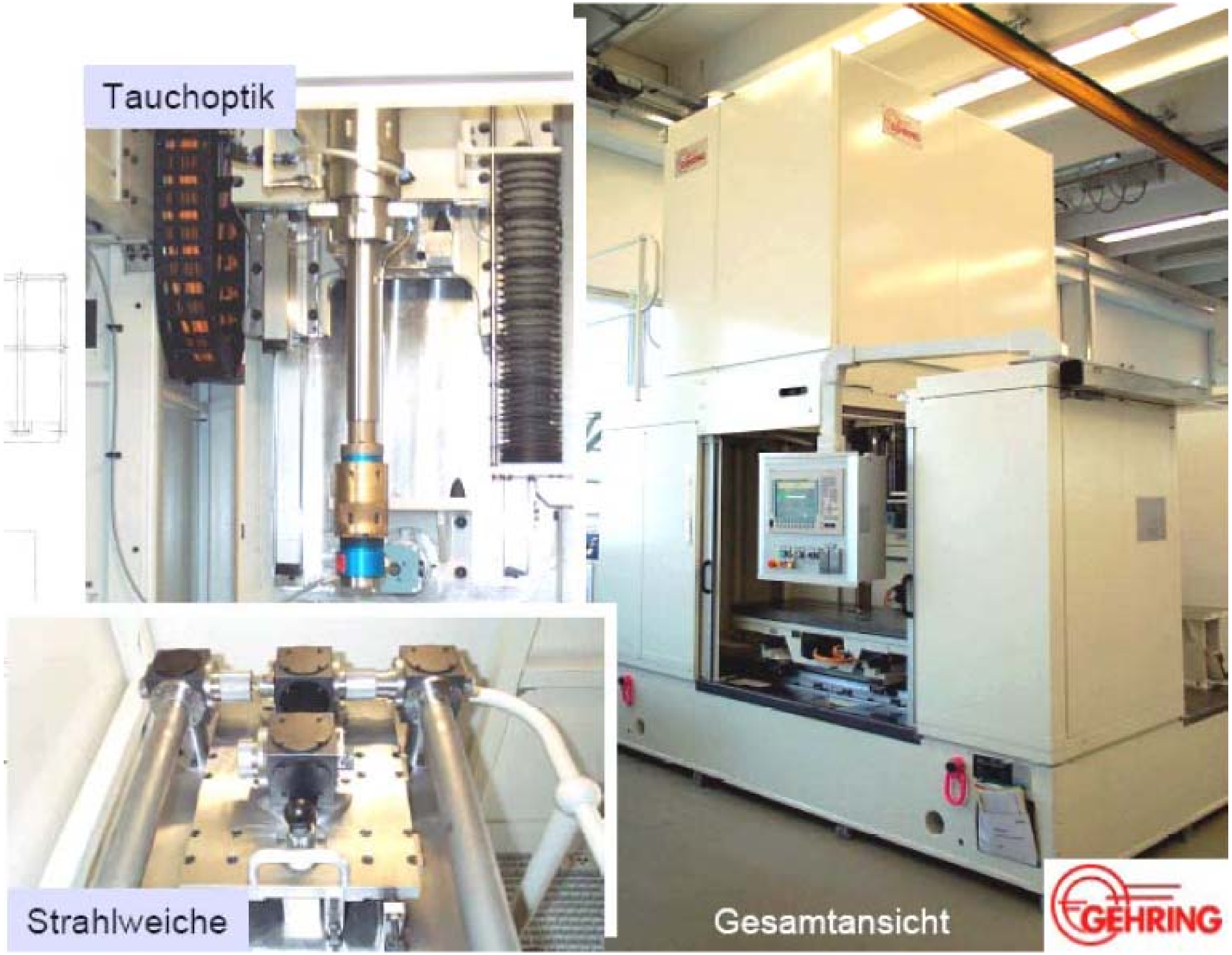




- DLC surfaces,
  nanostructured with fs-laser pulses
- MoS_2 layer to tune the friction properties of the nanostructured DLC surface, where the smallest
- $\mu_{min} = 0.02$

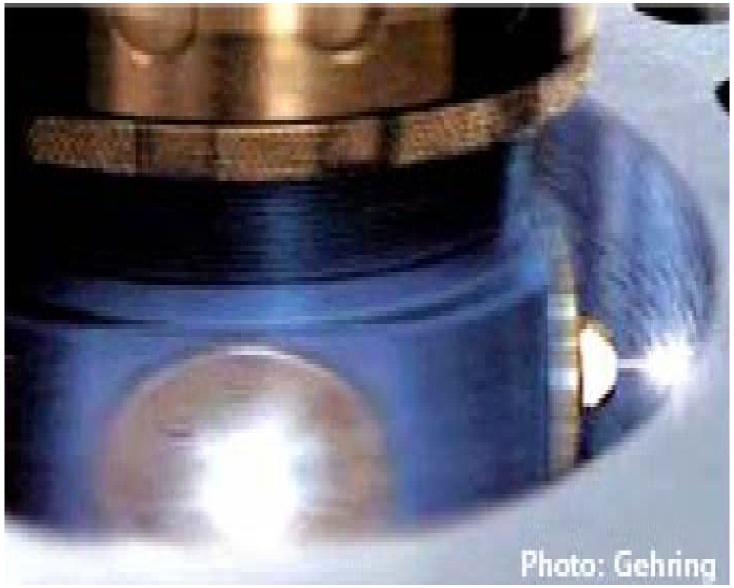
Applied Surface Science 254 (2008) 2364–2368

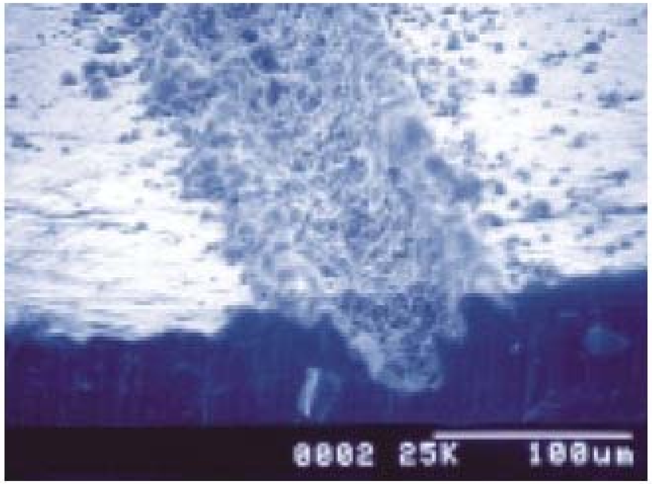
Laser honing (I)



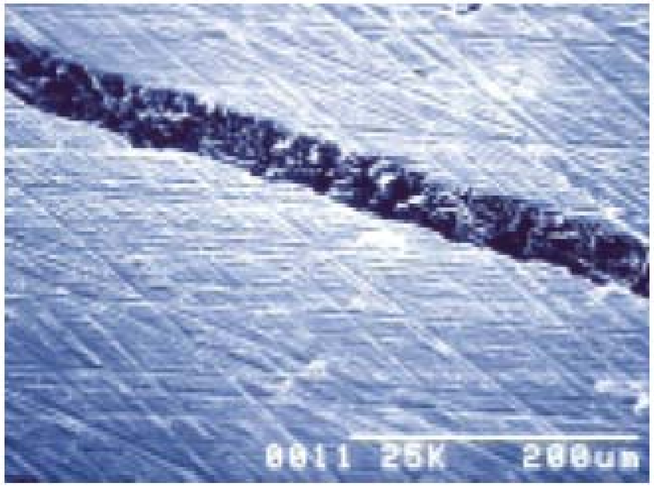
Laser honing (II)

- IR laser
- ns pulses





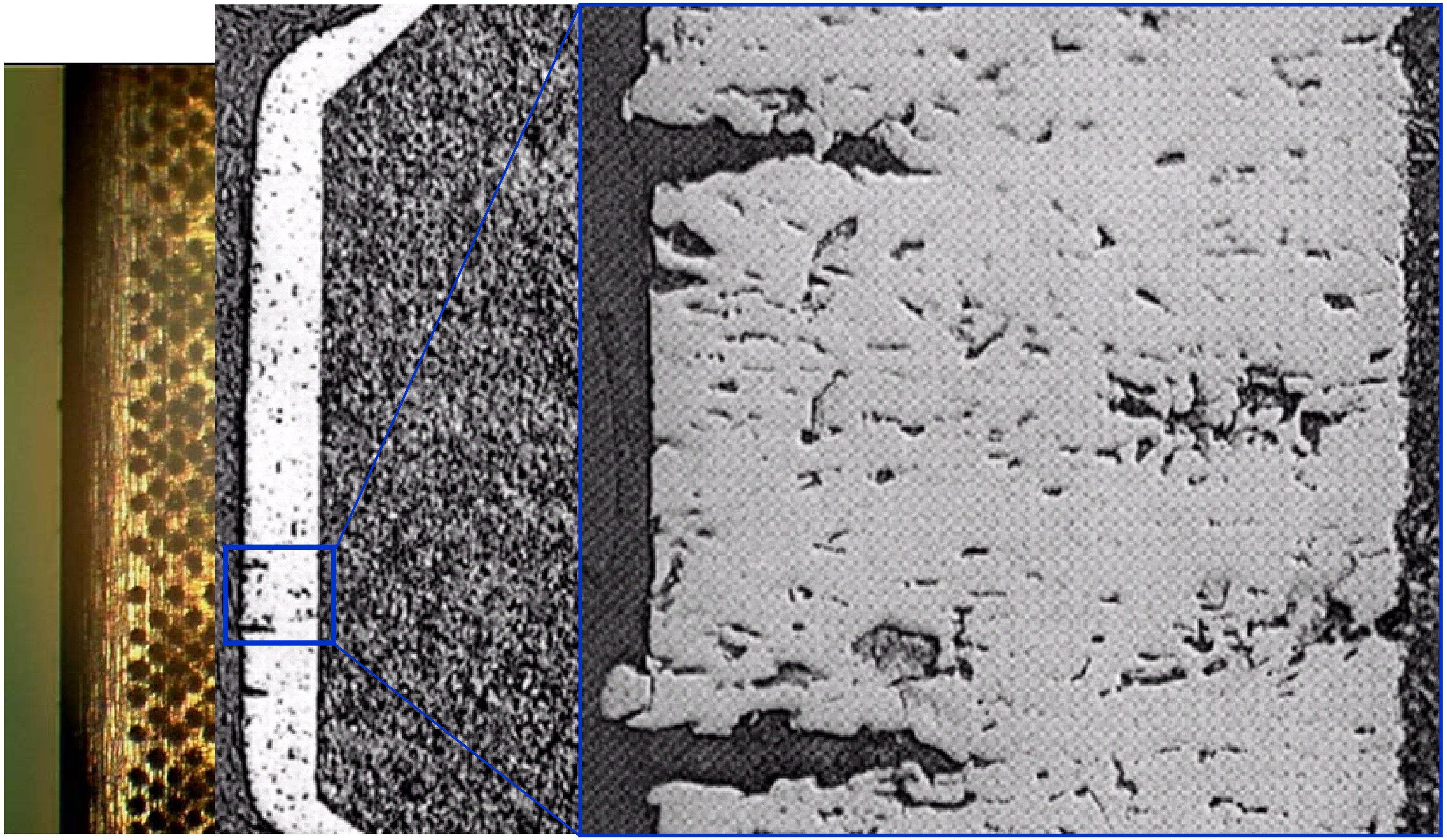
Structure after laser processing



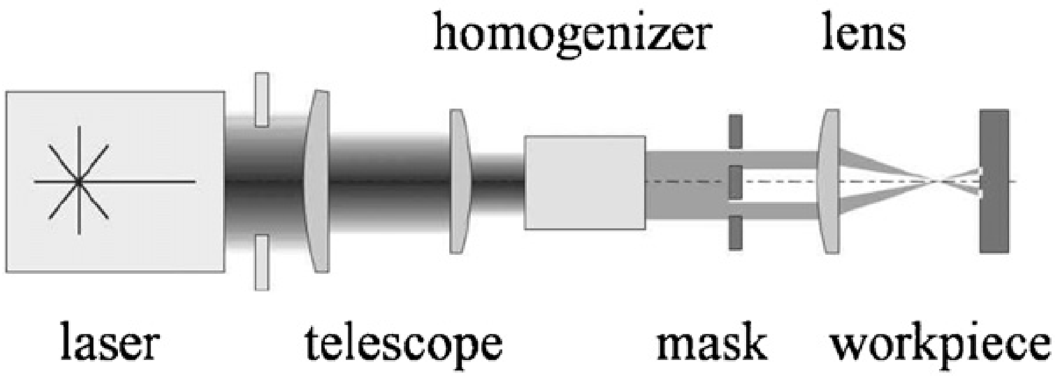
Structure after finish-machining

Laser texturing setup, piston rings

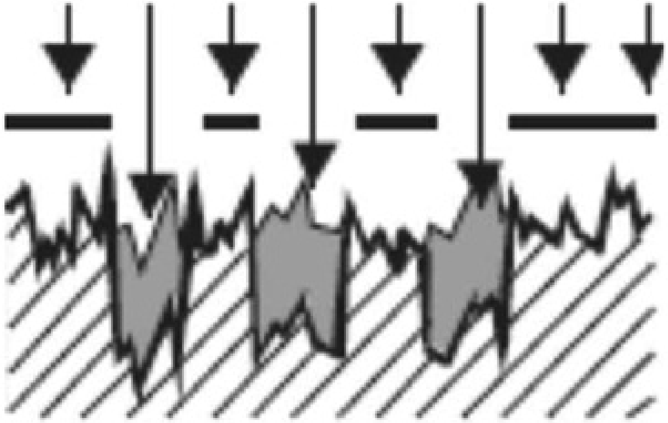
Piston rings: results

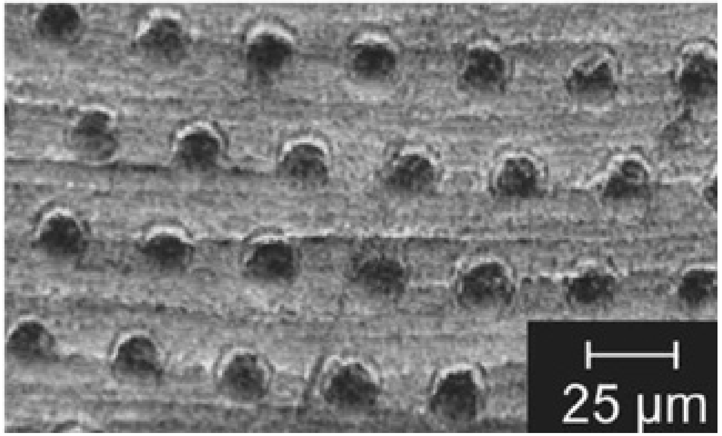


Tool life enhancement in cold forging



- excimer laser
- mask imaging

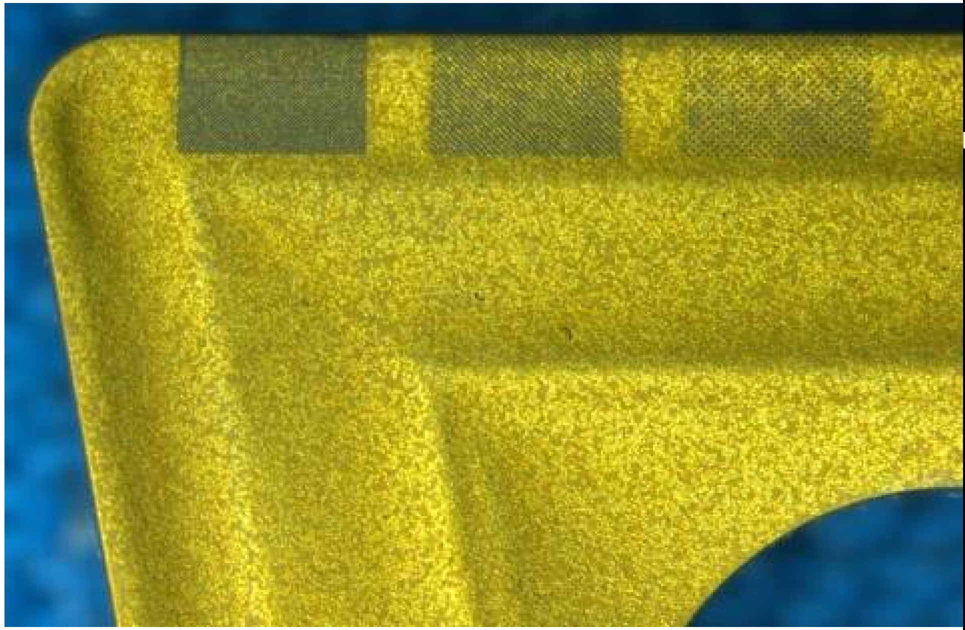


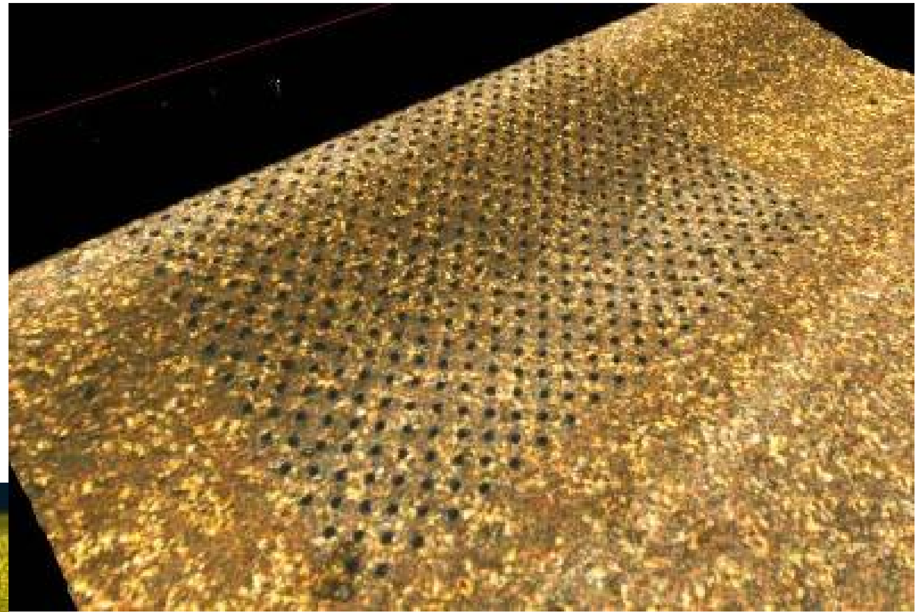


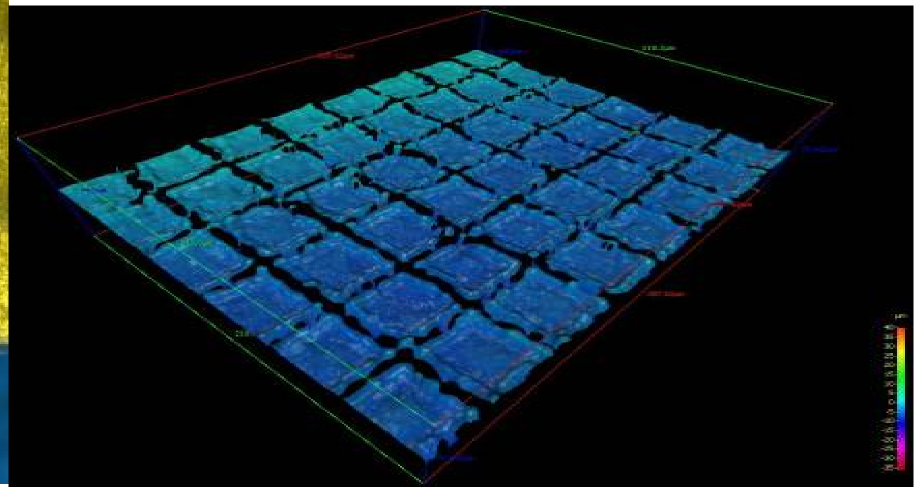
Journal of Engineering and Manufacturing 220 (2006) , 27–33

Laser texturing, uncoated cutting tools

- UV laser: 355 nm
- 15 – 25 ns
- 8 µm







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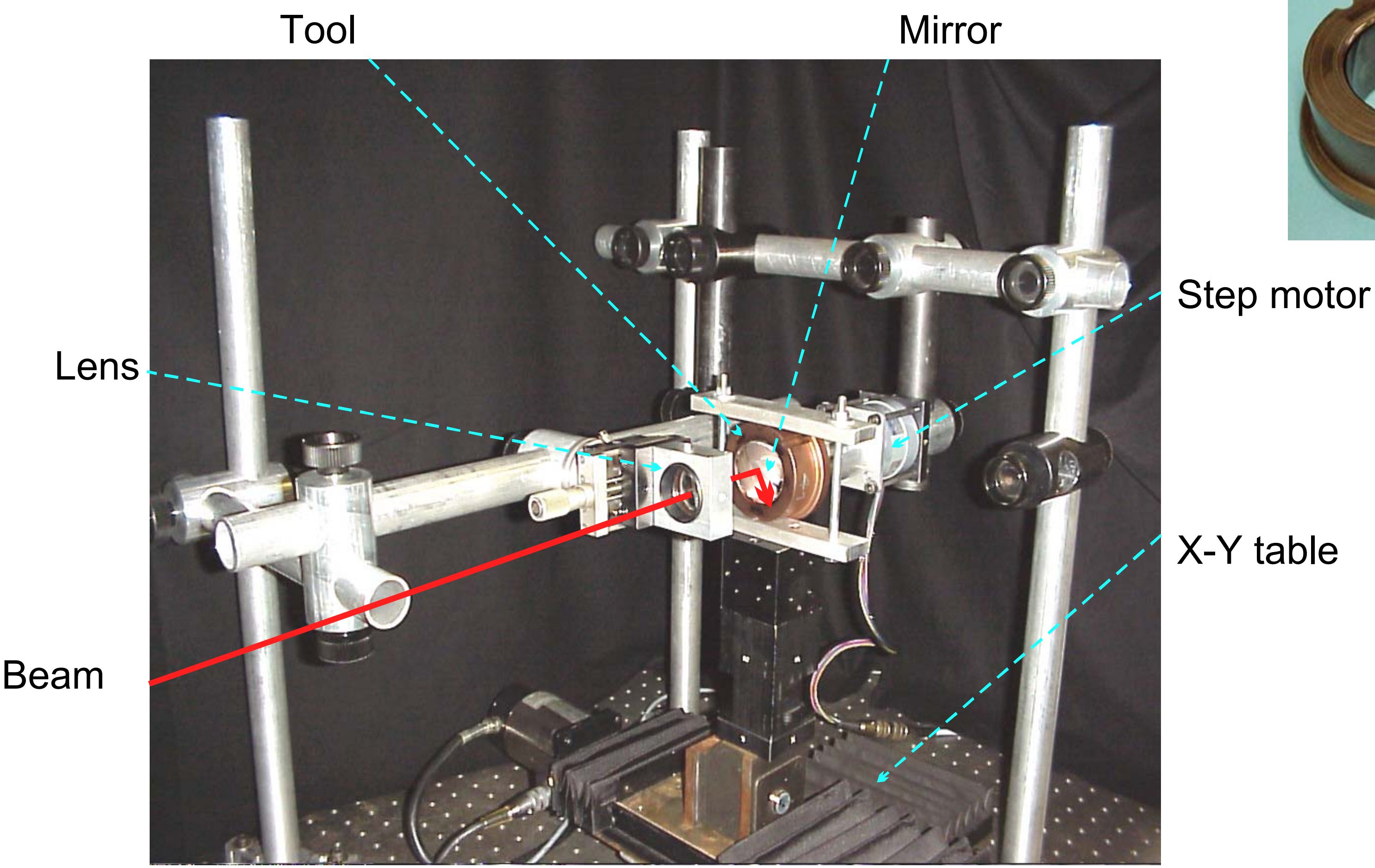
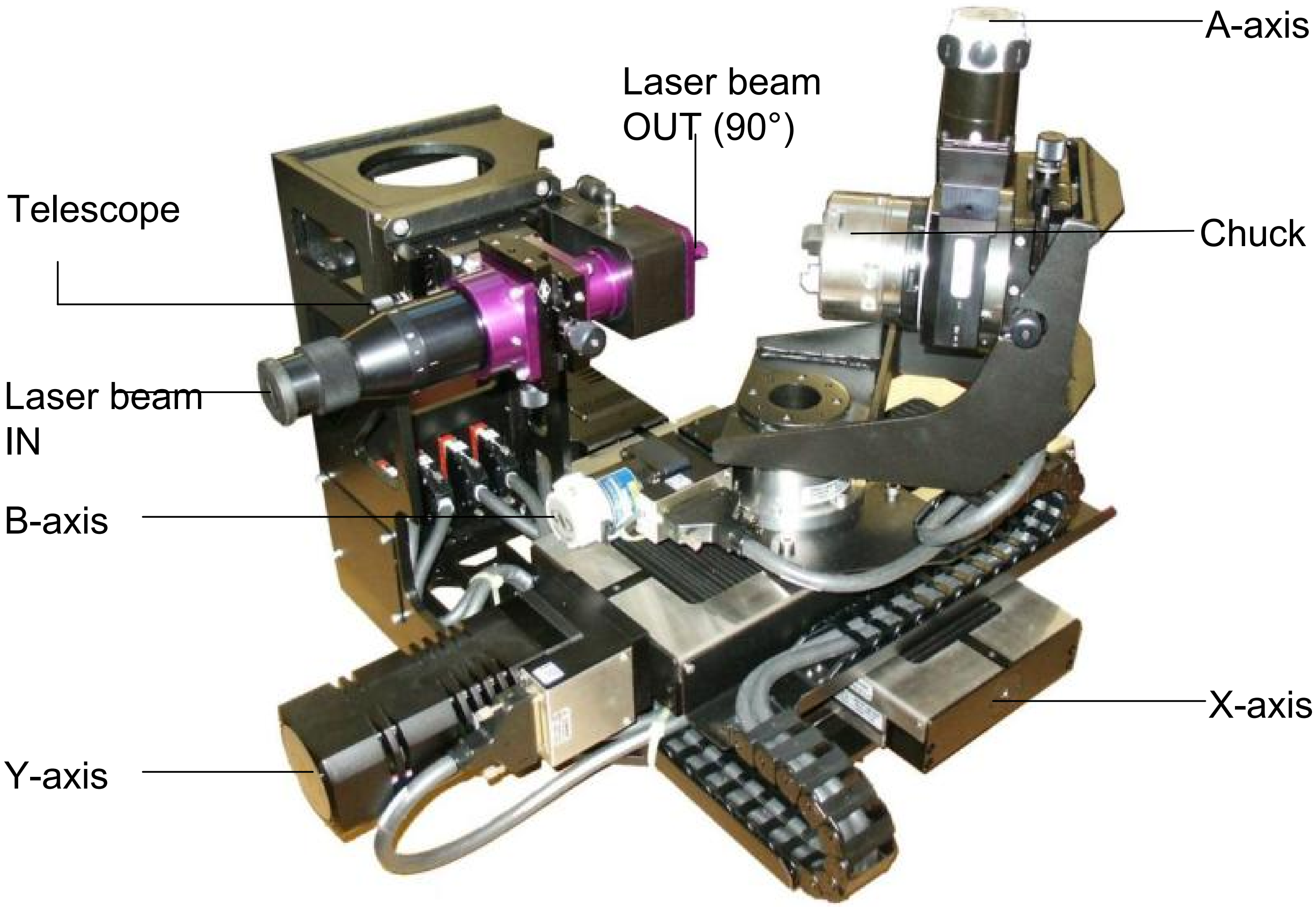
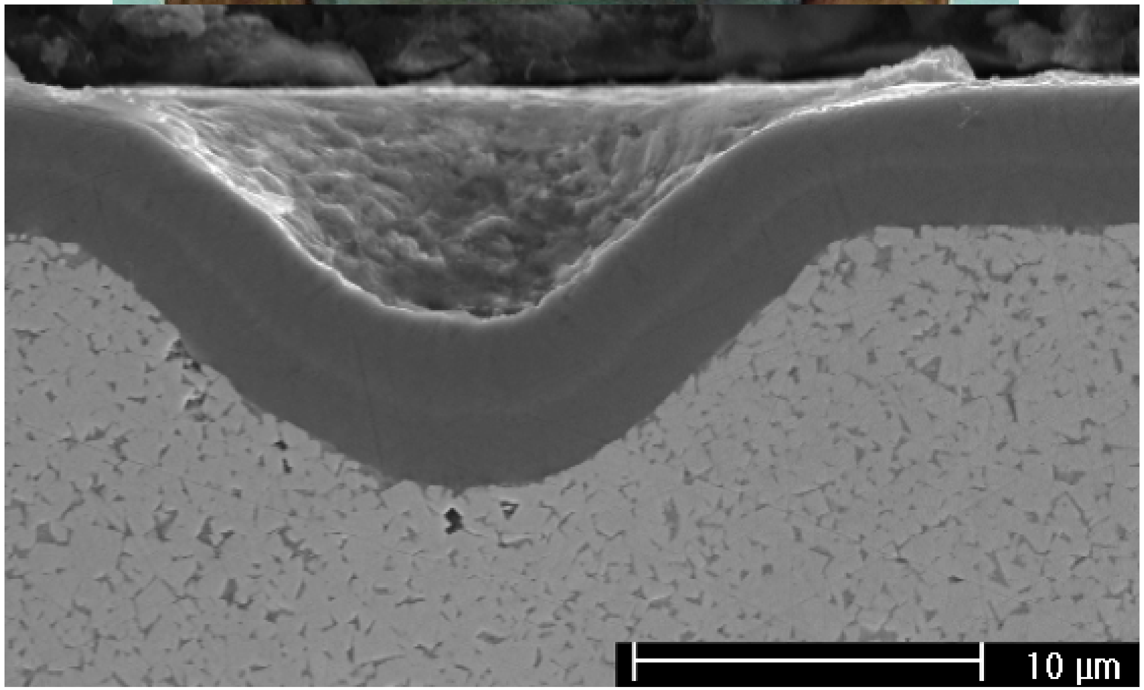
Texturing setup (tool)



Laser patterning: machine



Laser patterned tool

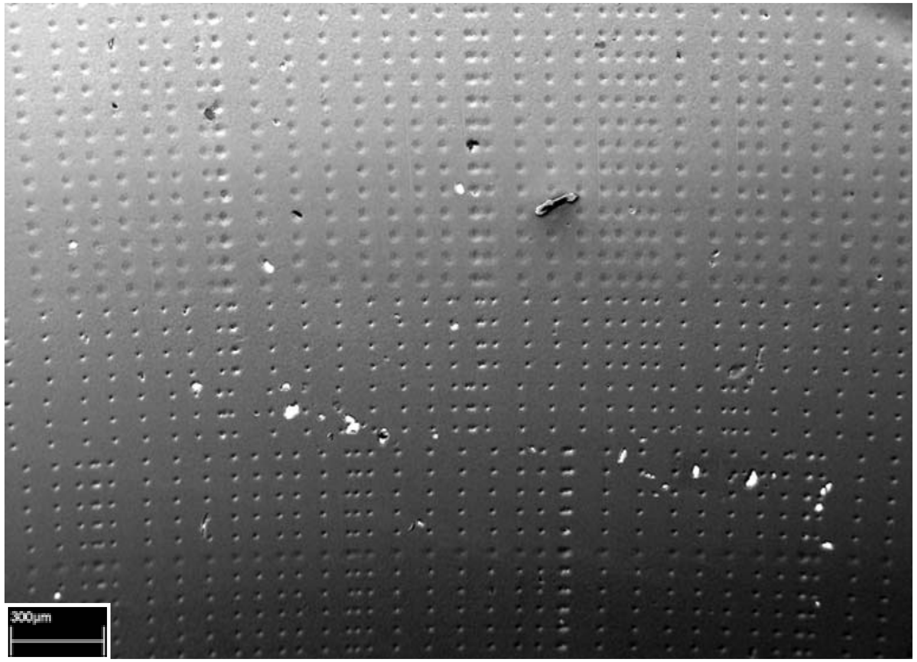


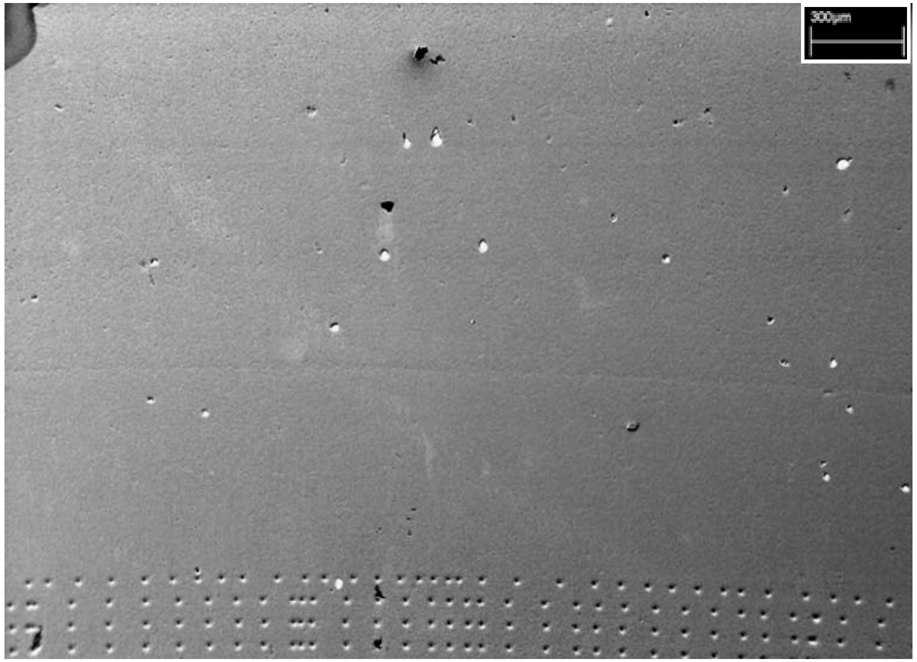
- WC-Co tool
- TiCN layer
- indirect processing

- spot size: 15 µm
- 200’000 pores

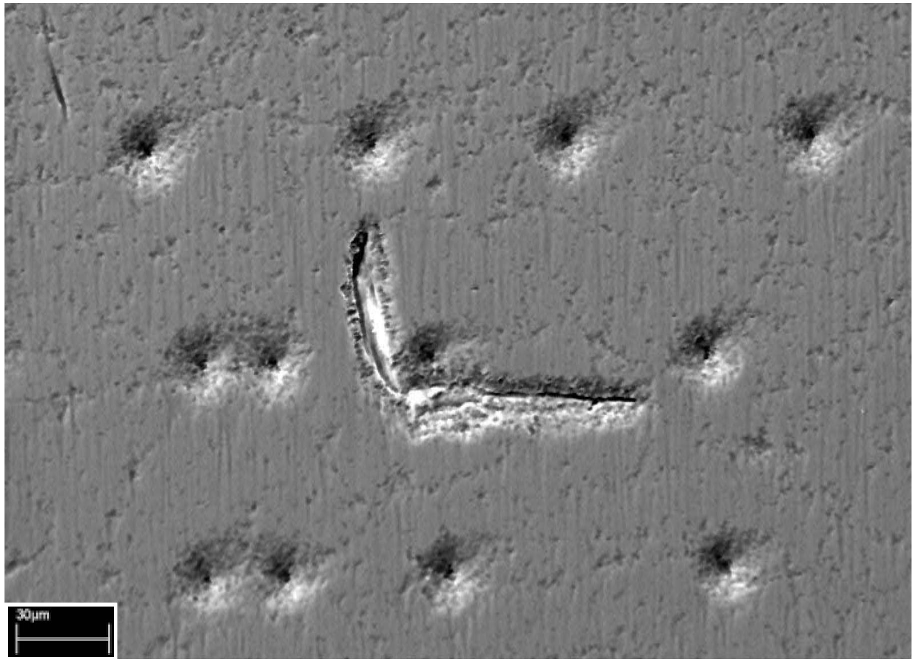
- reference: 500’000 parts

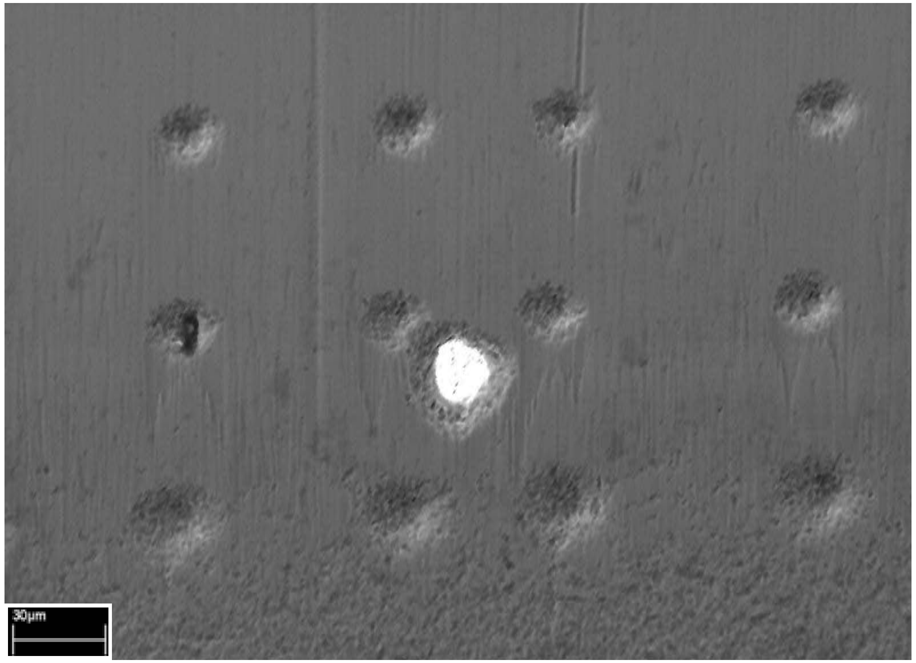
Tool after 13 millions parts (26 x T_{ref})



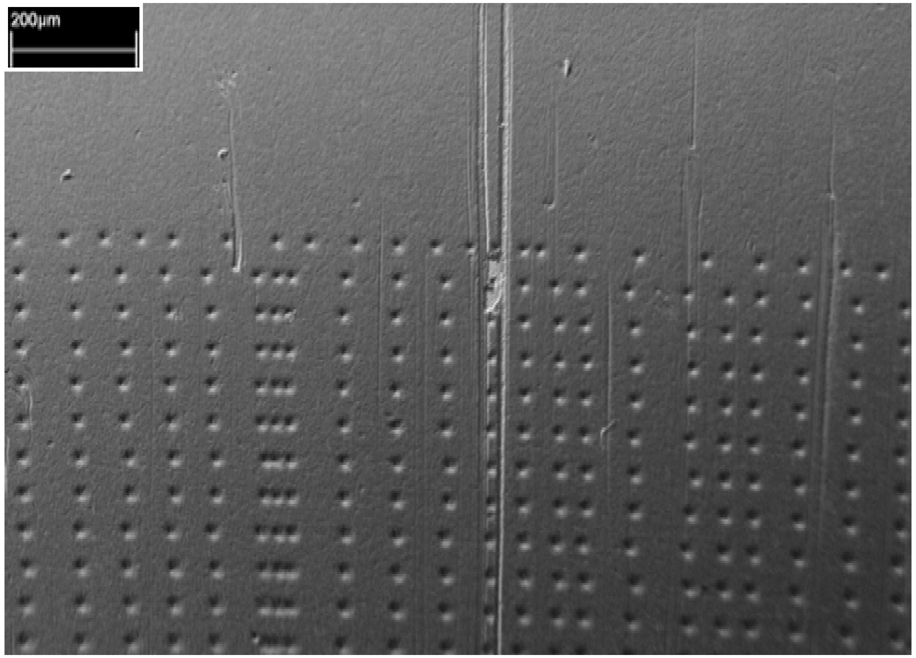


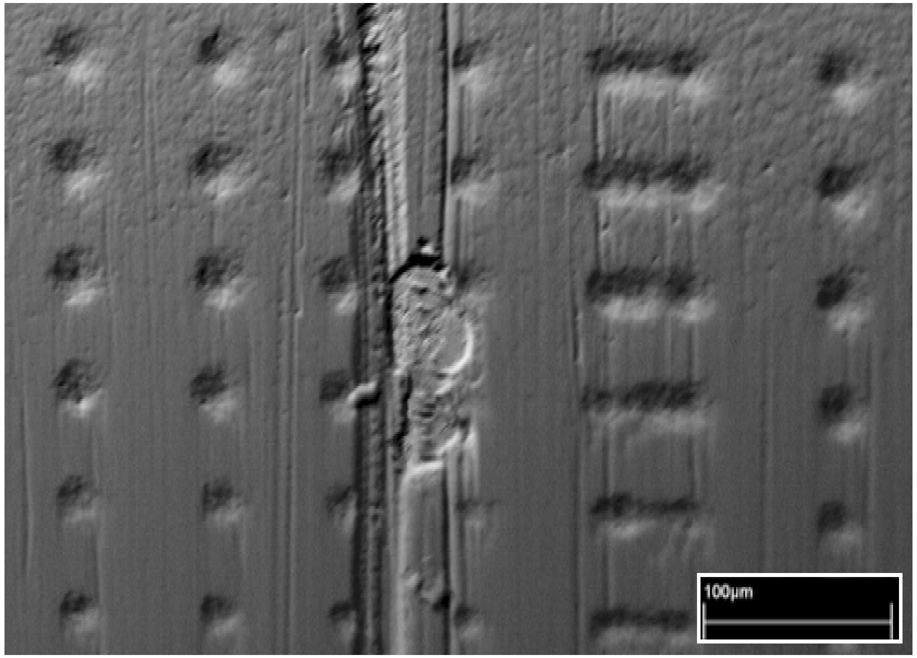
Tool after 13 millions parts



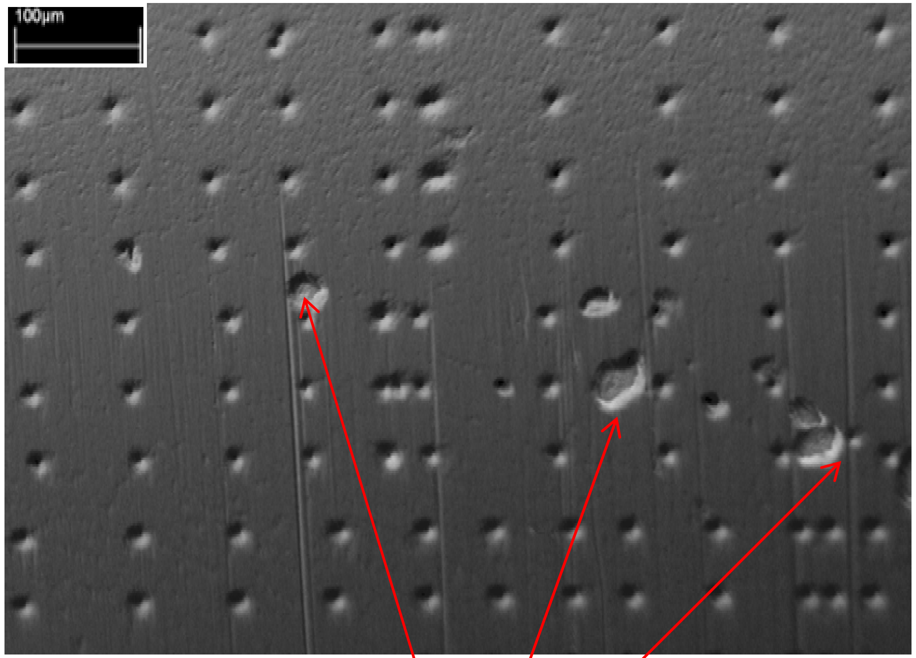


Tool after 34 millions parts (68 x T_{ref})

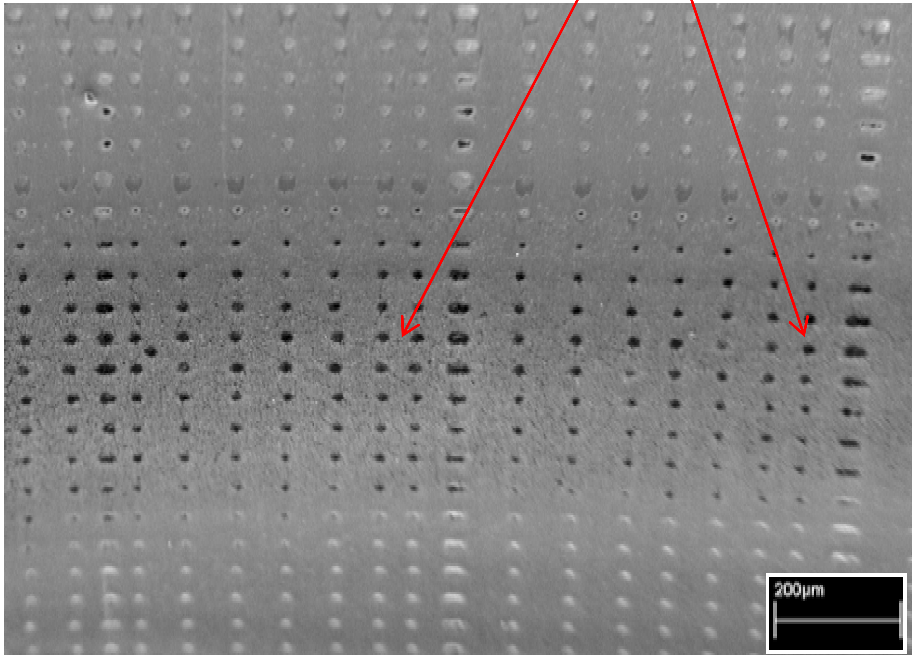




Tool after 34 millions parts



EDX: **Fe**



EDX: **W**

Case study: results

- Tool throughput: 49.6 mio. Parts
- Lifetime increase: 100 X

- Damages: randomly distributed
- Laser structure:
    - no crack points
    - no delamination centers
- EDX-Analyses on dimples:
    - lubricant reservoirs
    - particle traps

Conclusions

Background

- reducing wear / friction
- increasing lifetime of mechanical parts

Engineered tribological surfaces

- needed in a large variety of cases
- laser beam, a tool with certain advantages

Laser texturing …

… improves tribological behaviour of coated surfaces.

… does not compete, but completes coating procedures.

… can induce controlled structure changes.

Each particular application requires its own optimization.

Acknowledgements

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Dr. Hans Scheidiger, Dr. Beat Neuenschwander

CNRS – LP3, Marseille

Dr. Marc Sentis, Dr. Jörg Hermann

IWF, ETH Zürich

Dr. Fredy Kuster, Prof. Konrad Wegener