CeFEMA

Center of Physics and Engineering of Advanced Materials

Influence of Laser Surface Nanotexturing on the Friction of Silicon in Dry Sliding Conditions

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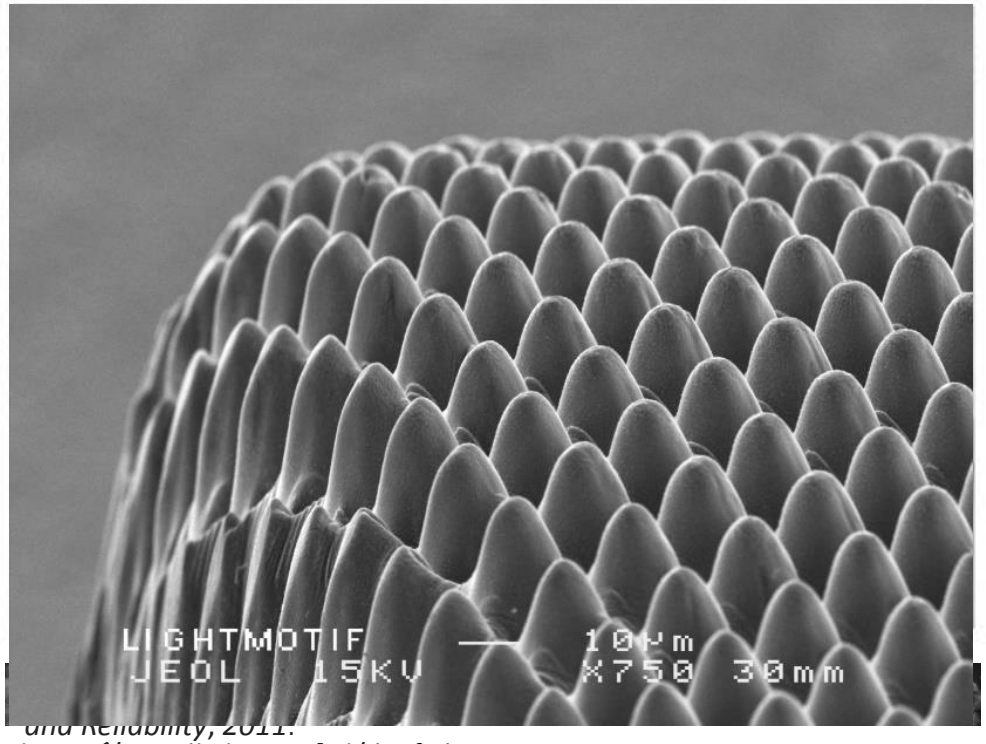
Outline

- Introduction
- Experimental Techniques
- Si/PTFE System
- Conclusions

Introduction

- **Control friction and wear by surface texturing**
- **Femtosecond lasers** – creation of a wide variety of structures with little thermal damage and surface contamination
- **LIPSS – Laser-Induced Periodic Surface Structures**
  - Parallel ripples that form on the surface of a wide variety of materials
- LIPSS affect surface properties (such as wettability, light reflectivity, bacteria adhesion and biofilm formation, **materials tribological behaviour**)



and Reliability, 2011.
https://www.lightmotif.com/texturing-laser

LIPSS influence on tribological performance is difficult to predict!

Si/PTFE Tribological Pair

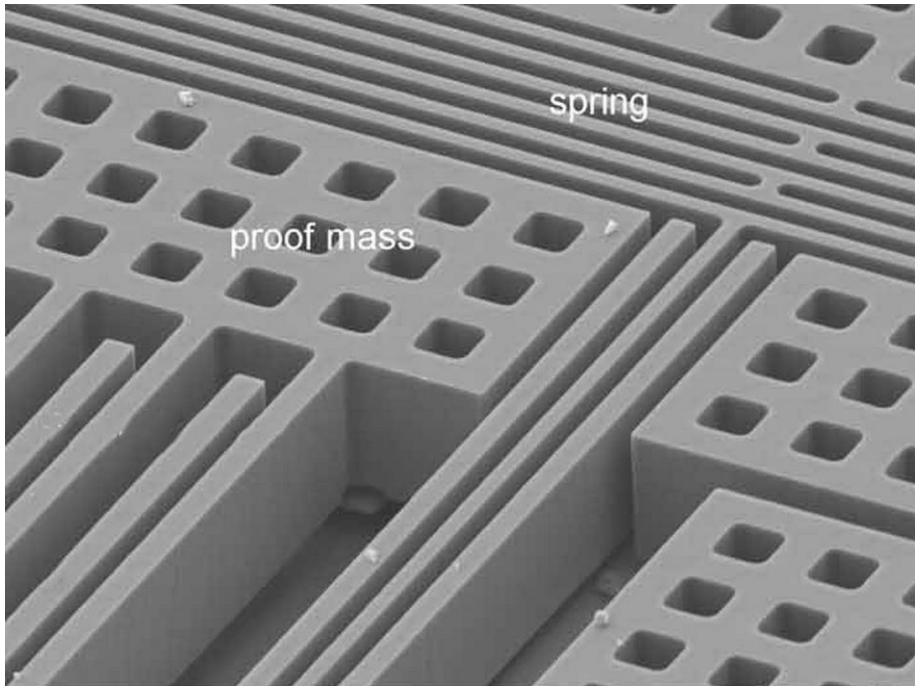
SI/PTFE

- Low strength polymer so extensive plastic deformation must occur
- Emphasize the influence of the surface roughness induced by the LIPSS on the plastic deformation and wear resistance

Silicon: Primary MEMS material

- Piezoresistive pressure sensors; accelerometers, mechanical resonators,….

PTFE: Hybrid microdevices



Accelerometer – XY sensor detail. Taken from: http://gph.is/2avxPHd

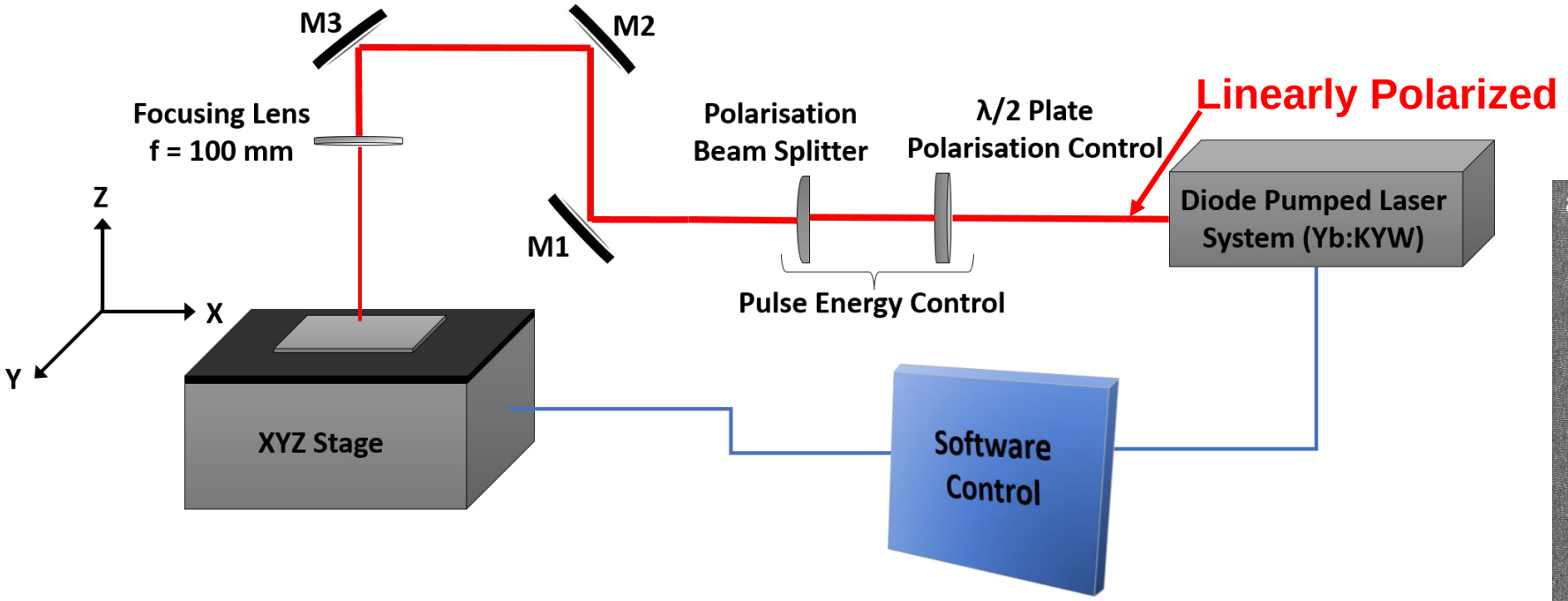
PTFE: Polytetrafluoroethylene

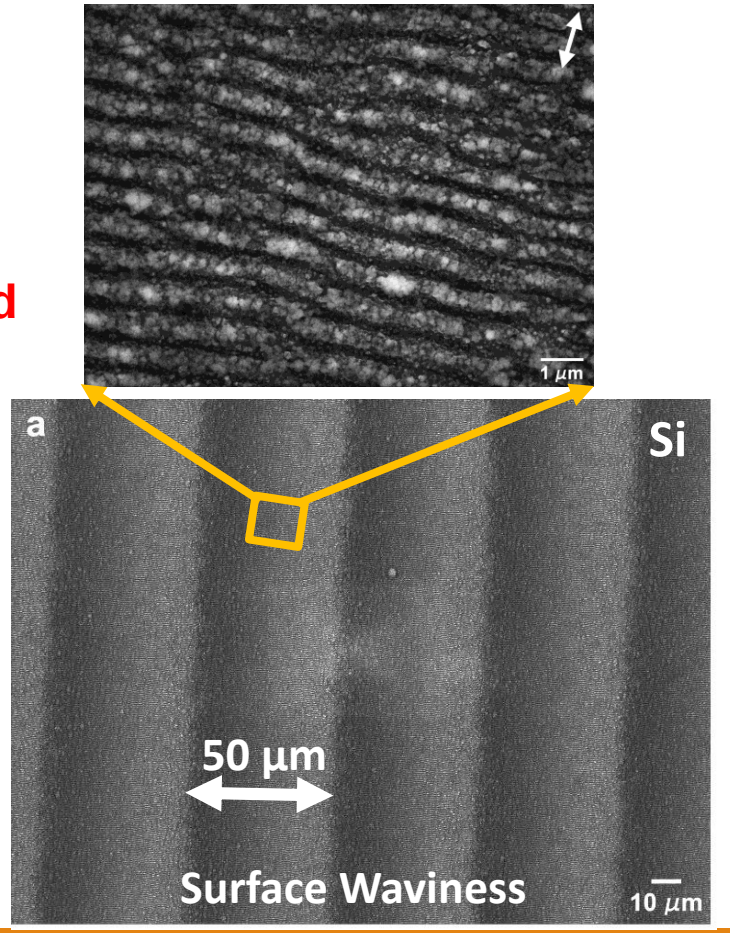
Fs Laser

- <111> single crystal wafer of p-doped Silicon
- Direct writing technique – non-stationary regime
- Yb:KYW chirped-pulse regenerative amplification laser system

$$\lambda_{laser} = 1030\ nm;\ \tau = 560\ fs$$

P_{laser} (mW)	F (Jcm^{-2})	N_{pulses} per spot
125	0.32	40



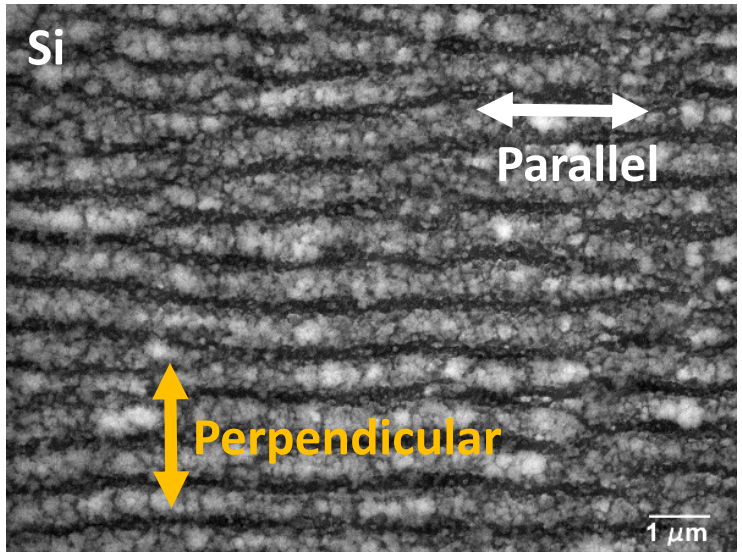


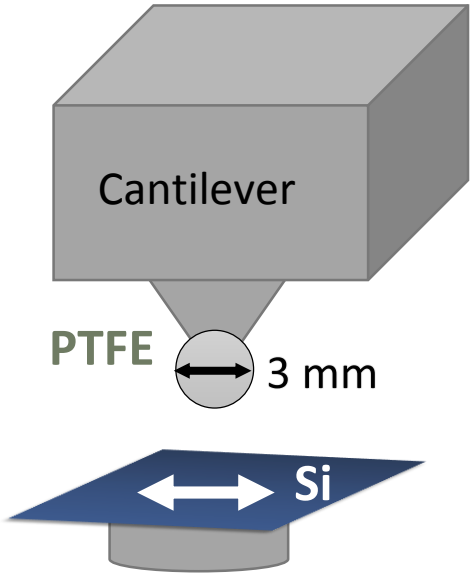
Friction Tests

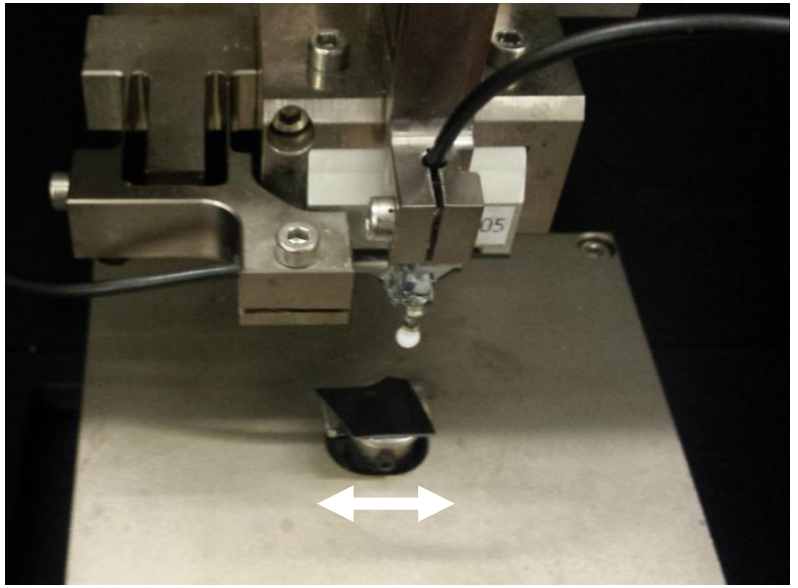
- Nanotribometer – Friction Coefficient
- PTFE counterbodies (3 mm diameter)
- Textured specimens:
  - Vary number of sliding cycles: 50 to 1000

Polished and Textured Specimens

v (cm/s)	A (mm)	Loads (mN)	Cycles
1	1	2, 5, 10 and 25	1000

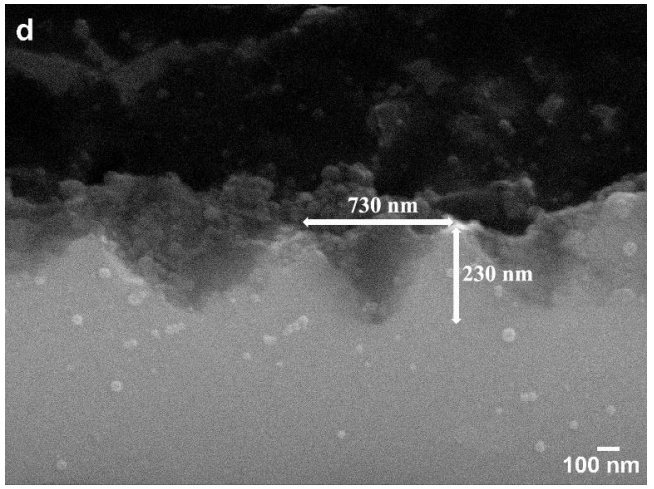






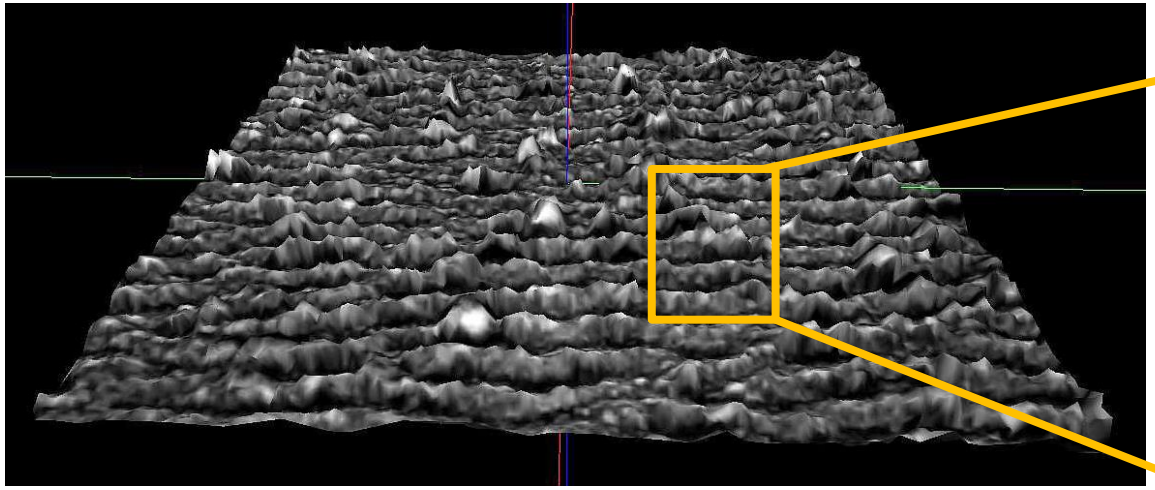
Surface Characterization

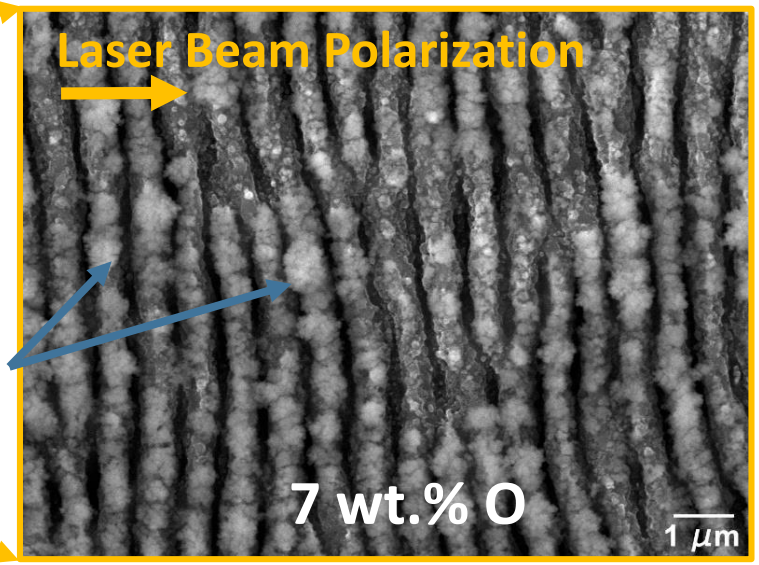
- Laser textured surfaces and wear tracks
- Field Emission Gun Scanning Electron Microscopy (FEG-SEM)
  - Energy-Dispersive X-ray Spectroscopy (EDS)



Cross-section of the LIPSS

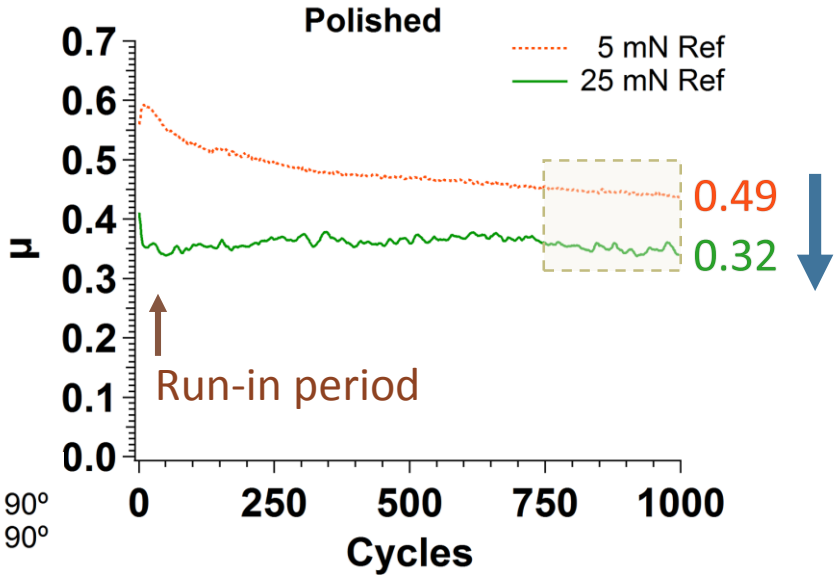
LIPSS Processed Surfaces

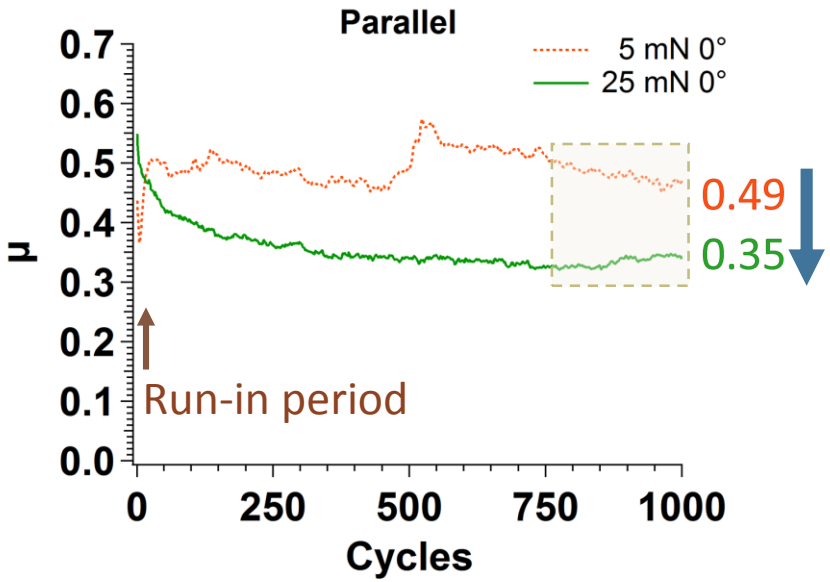

3D Profile of the textured surface by analysis of the stereoscopic pairs using the AliconaMex software.

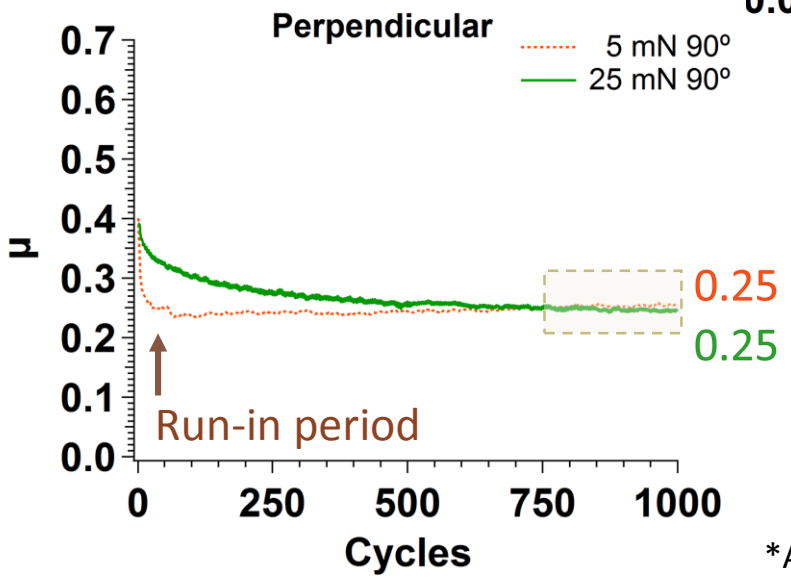


Si/PTFE System – Friction Tests

Sample	Variation of μ with Cycles
Polished	Decreases at 5 mN; Approximately constant at 25 mN
Paralell	Approximately constant at 5 mN; Decreases at 25 mN
Perpendicular	



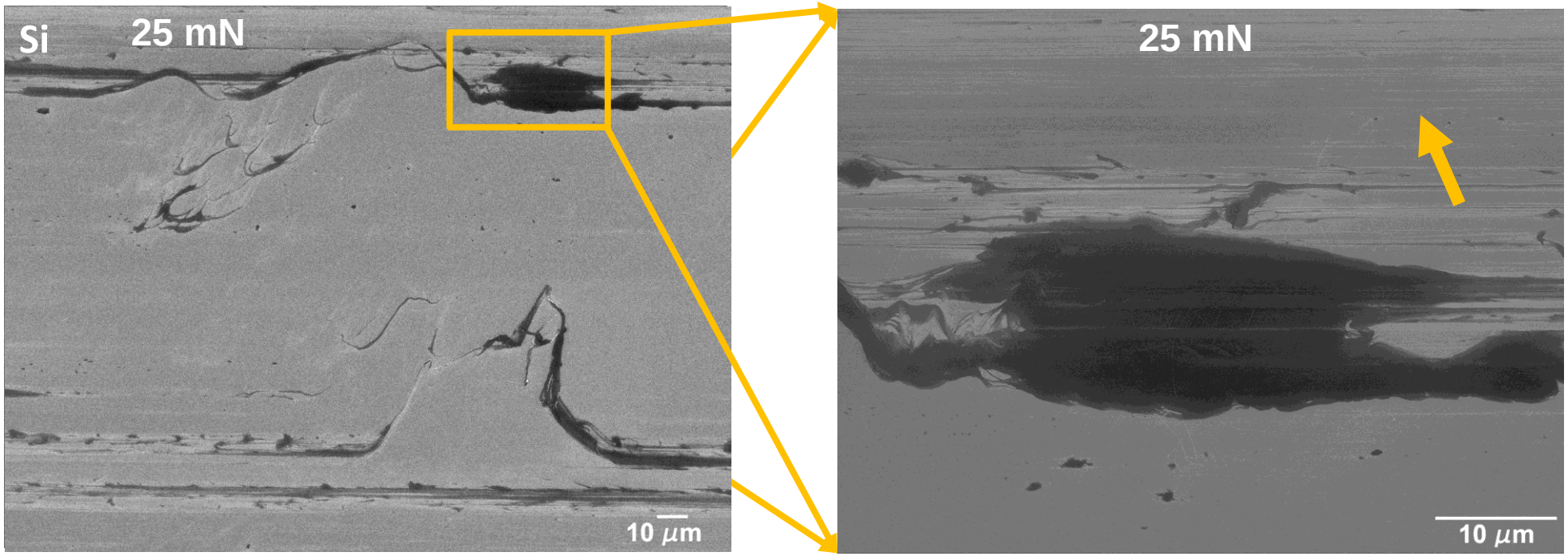




Lowest values of friction coefficient in the perpendicular direction!

*Average friction coefficient values calculated from the average of 3 tests between 750 and 1000 cycles.

Wear Mechanisms – Polished Silicon



- **5 mN**: Thin PTFE film with a fibrous structure, lumps and ribbons
- **25 mN**: Thin fibrous film together with thick PTFE layers formed by agglomeration of lumps
- Lumps form due to the fracture of PTFE in the low ductility regime
- Area covered by transferred PTFE increases with increasing load, decreasing the μ

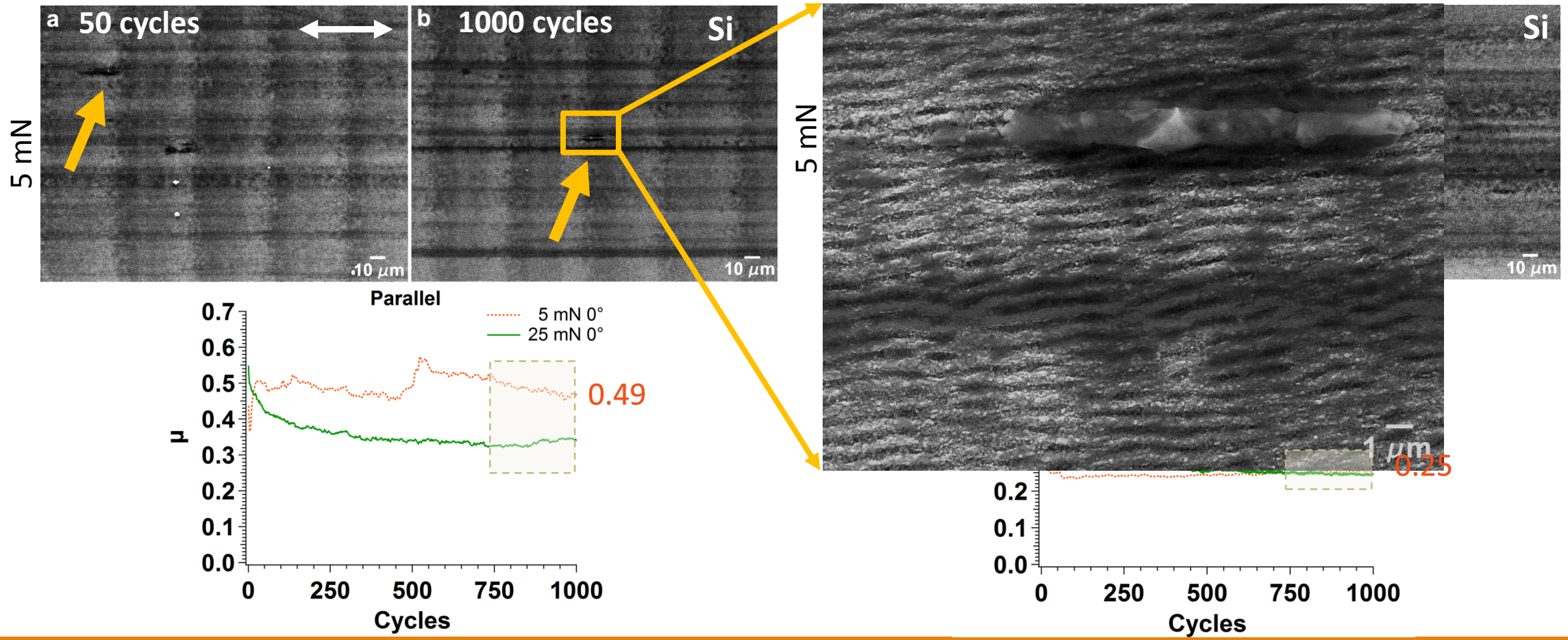
Wear Mechanisms – Textured Silicon LL

Parallel Sliding Direction

Thin PTFE film and thicker layers irregularly distributed;
Large wear particles indicate random fracture of PTFE

Perpendicular Sliding Direction

Thin film and thicker layers are more uniformly distributed;
Large PTFE particles are less frequent

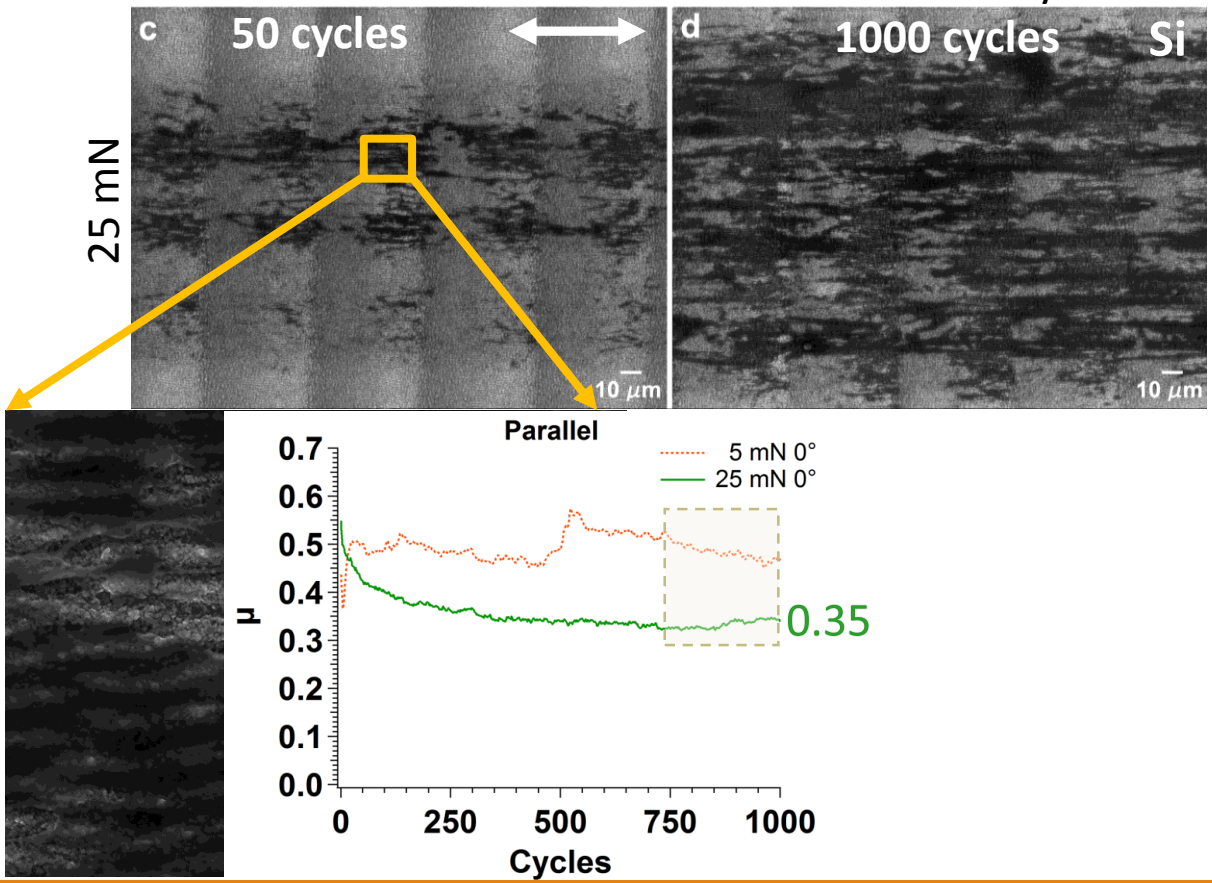


Wear Mechanisms – Textured Silicon HL

Parallel Sliding Direction

Thick PTFE layers irregularly distributed due to the surface waviness (transverse to sliding);

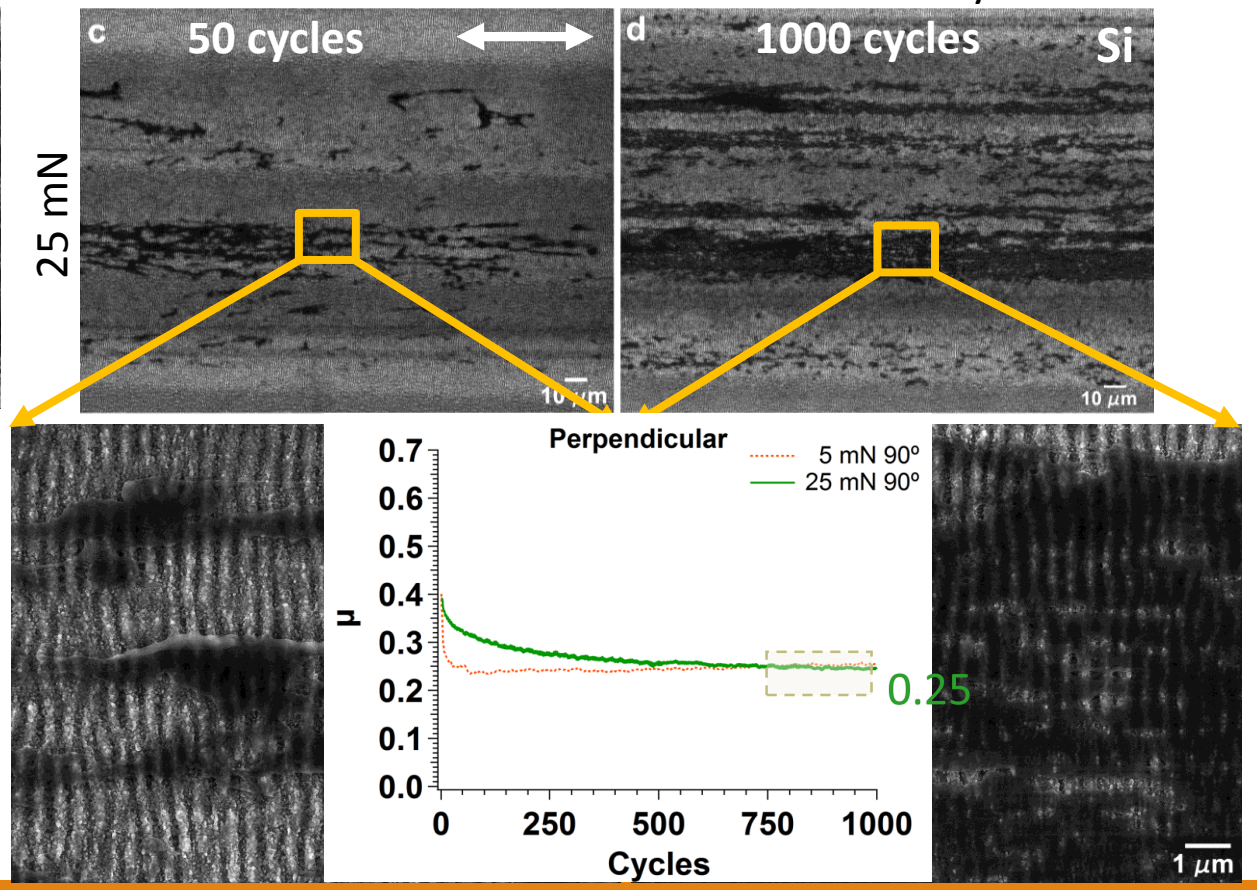
PTFE covered area increases with number of cycles



Perpendicular Sliding Direction

PTFE layers more uniformly distributed in the sliding direction;

PTFE covered area increases with number of cycles



Si/PTFE System – Summary

- **Polished Si**: Friction coefficient controlled by the area covered by PTFE.
- **Textured Si**:
  - The texture favours abrasive wear of PTFE and increases the amount of transferred material
  - The PTFE transferred layer concentrates at the crests of the waviness
- **Parallel sliding direction:** The transferred layer is discontinuous in the sliding direction
- **Perpendicular sliding direction:** The transferred layer is continuous in the sliding direction
- The friction coefficient decreases due to the formation of a continuous film of PTFE on the surface. The presence of LIPSS favours the formation of this film but its effect is opposed by the presence of the waviness created by track overlapping

Lowest values of friction coefficient in the perpendicular direction!

Conclusions

- The effect of LIPSS on the friction coefficient of Si depends critically on the properties of the materials involved, on the surface topography and on the testing parameters.
- LIPSS may lead to a decrease of the friction coefficient by favouring the formation of low shear strength films at the interface between the two contacting bodies.
- In order to achieve the maximum benefit, reduce surface waviness to a minimum.

Acknowledgements

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Thank You!