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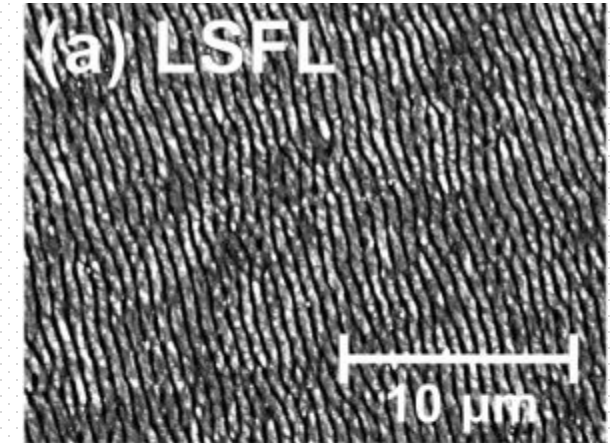
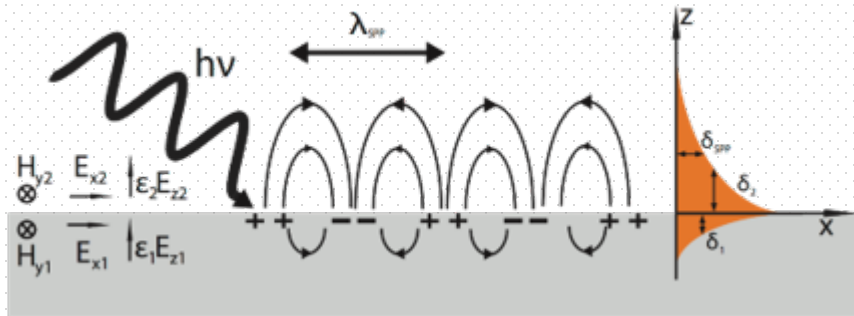
Success factors for industrial application of Laser Induced Periodic Surface Structures



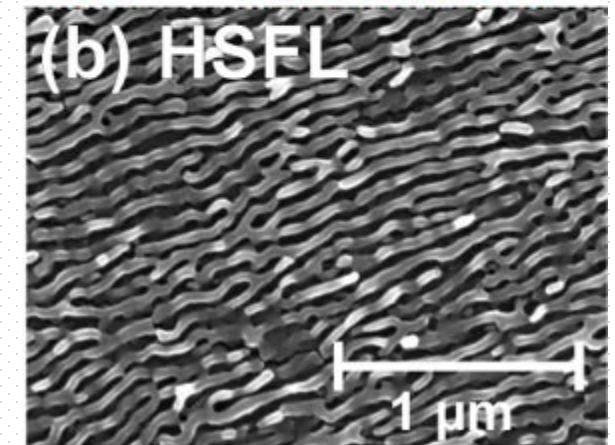
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Laser Induced Periodic Surface Structures

- Laser induced periodic Surface structures (LIPSS) are nanoscale patterns produced upon linearly polarized laser irradiation.
- Easy to generate on a wide range of materials ranging from dielectrics to metals
- Interference pattern generated by the interaction between a Surface plasmon polariton (SPP) and the laser radiation



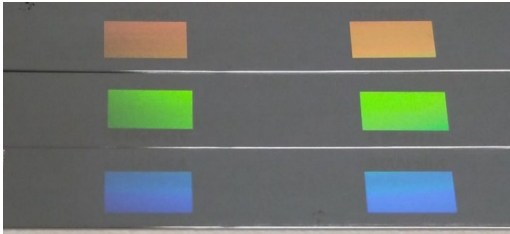
Polarization



LIPSS Applications

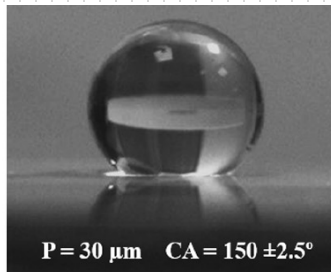
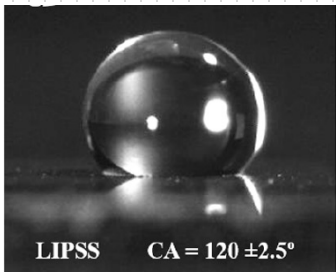
Aesthetical Applications

- Structural Color
- Soft-touch surfaces



Liquid Control & Surface Wetting

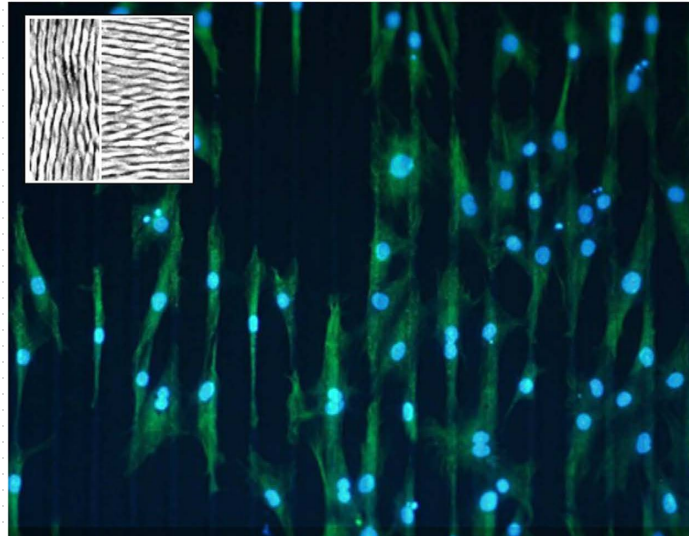
- Superhydrophobic & Hydrophilic Surfaces
- Self-cleaning surfaces
- Directional fluid transport



M. Martínez-Calderon, et al., Appl. Surf. Sci. 2015

Biomedical Applications

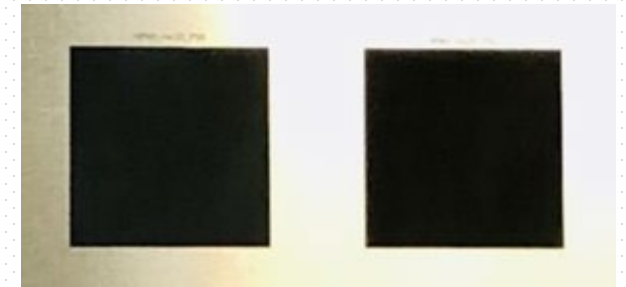
- Cell Growth & Differentiation
- Antibacterial Surfaces



M. Martínez-Calderon, et al., Sci. Rep. 2016

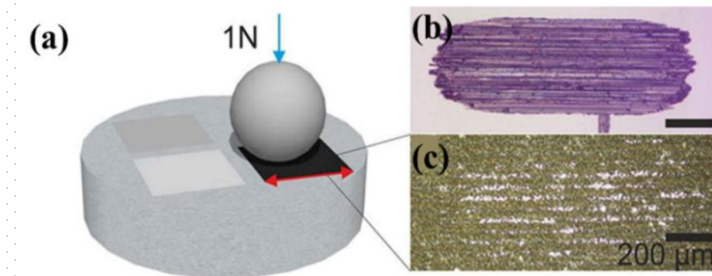
Optical Applications

- Polarization Control
- SPR Sensors
- Enhanced Light Absorption
- Gratings & Diffraction Elements



Tribological Applications

- Reduction of Friction
- Reduction of Wear
- Management of Lubricants



Florian, C. et al. Appl. Phys. 2020, 126, 266.



By leveraging the precise and customizable nature of LIPSS industries can develop innovative solutions that enhance the performance and functionality of their products.

Success factors for industrial adoption of new laser processes

Technical Performance & Reliability

Precision and Accuracy,
Consistency,
Speed and Efficiency.

Regulatory Compliance and Safety

with industry-specific
regulations and standards

Application Suitability

Tangible benefits such as
improved product quality
or new capabilities.

Market Demand

It should address a clear
need or gap, and provide a
competitive advantage

Sustainability & Environmental Impact

Energy efficiency,
Waste reduction,
environmentally
friendly.

Cost-effectiveness

The cost should be justifiable
with a clear return on
investment (ROI).

Integration with Existing Systems

Compatibility and
ease of integration

Scalability

Scalable to handle different
volumes and adaptable to
different product types without
significant reconfiguration.

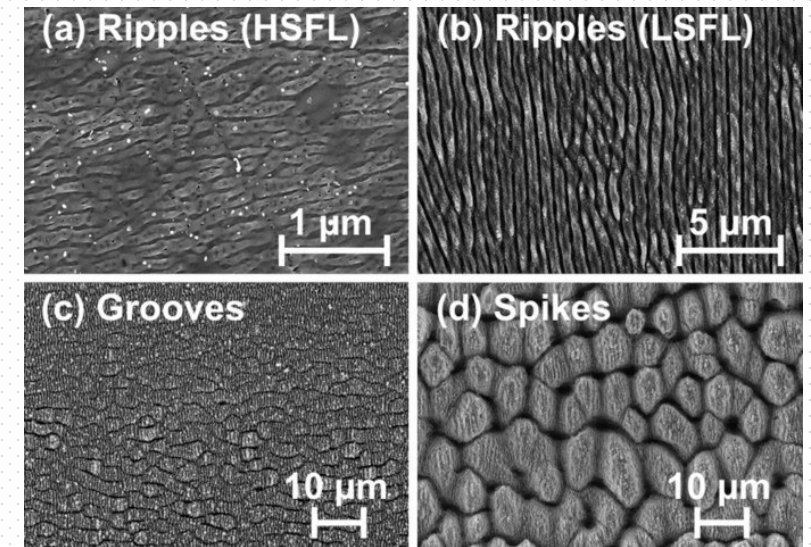
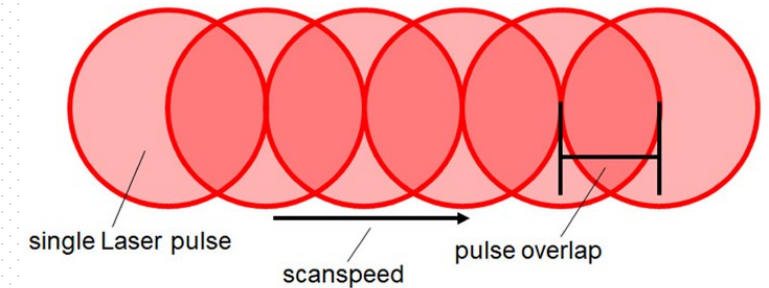
Some limitations of LIPSS

- Processing Speed and Scalability:

- The formation of LIPSS requires multiple laser pulses per spot → throughput limited
- The precise control needed for LIPSS is challenging to maintain over large surfaces, affecting uniformity and consistency.

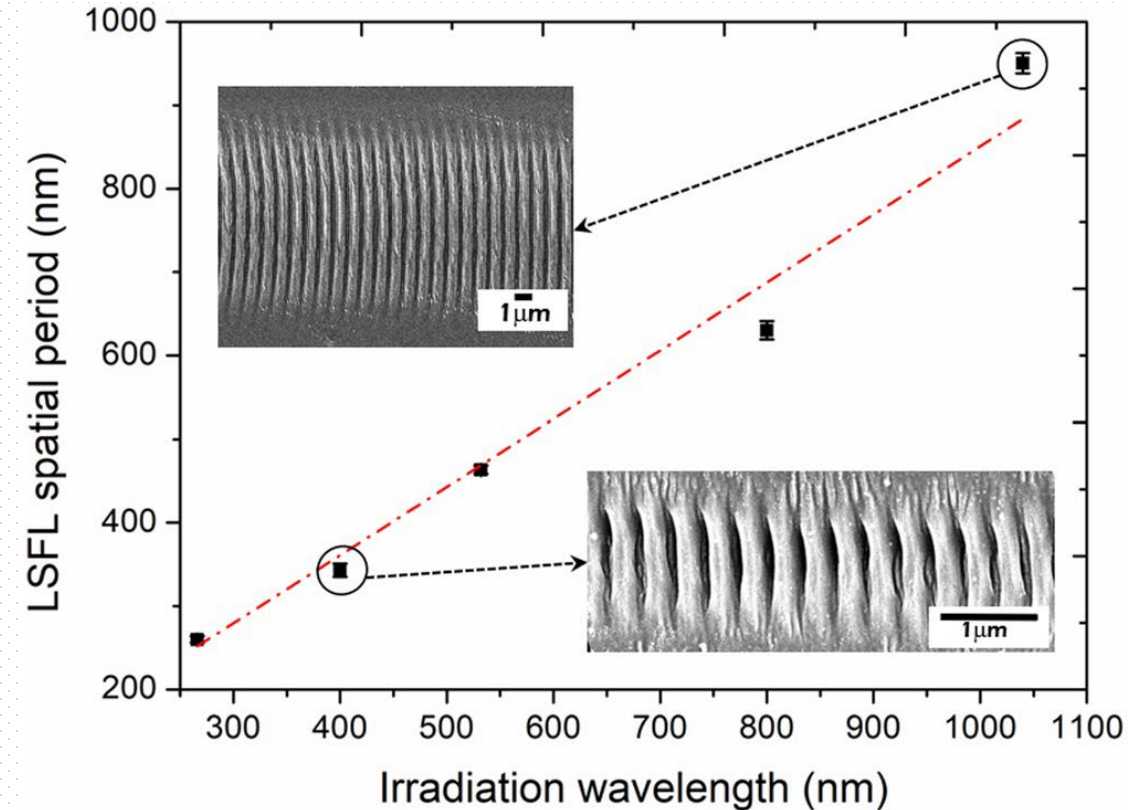
- Material-Specific Limitations:

- Different materials respond differently to laser irradiation.
- The efficiency and quality of LIPSS vary widely depending on the material



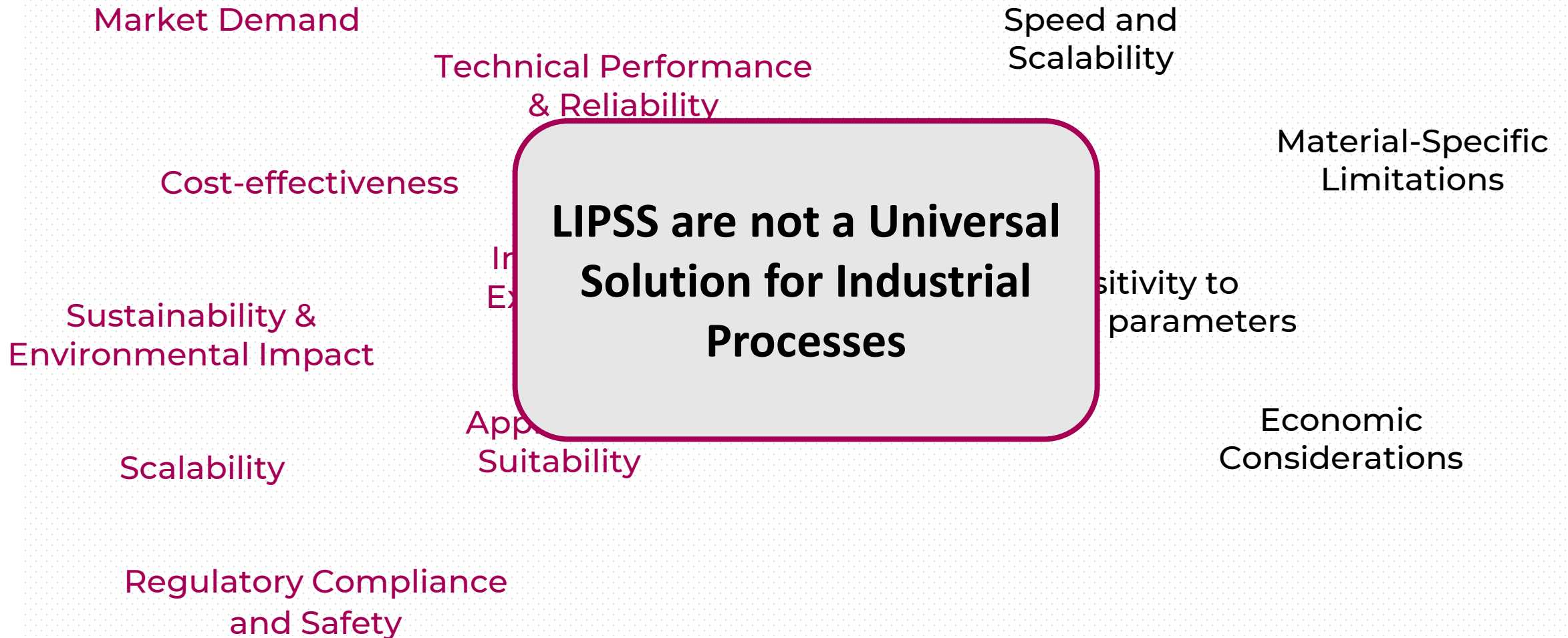
Some limitations of LIPSS

- Process Parameters:
 - LIPSS formation is highly sensitive to laser parameters (wavelength, pulse duration, fluence, and polarization).
 - Finding the optimal set of parameters can be a complex and time-consuming process.
- Economic Considerations:
 - High Initial Costs



M. Martínez-Calderon, et al., Sci. Rep. 2018

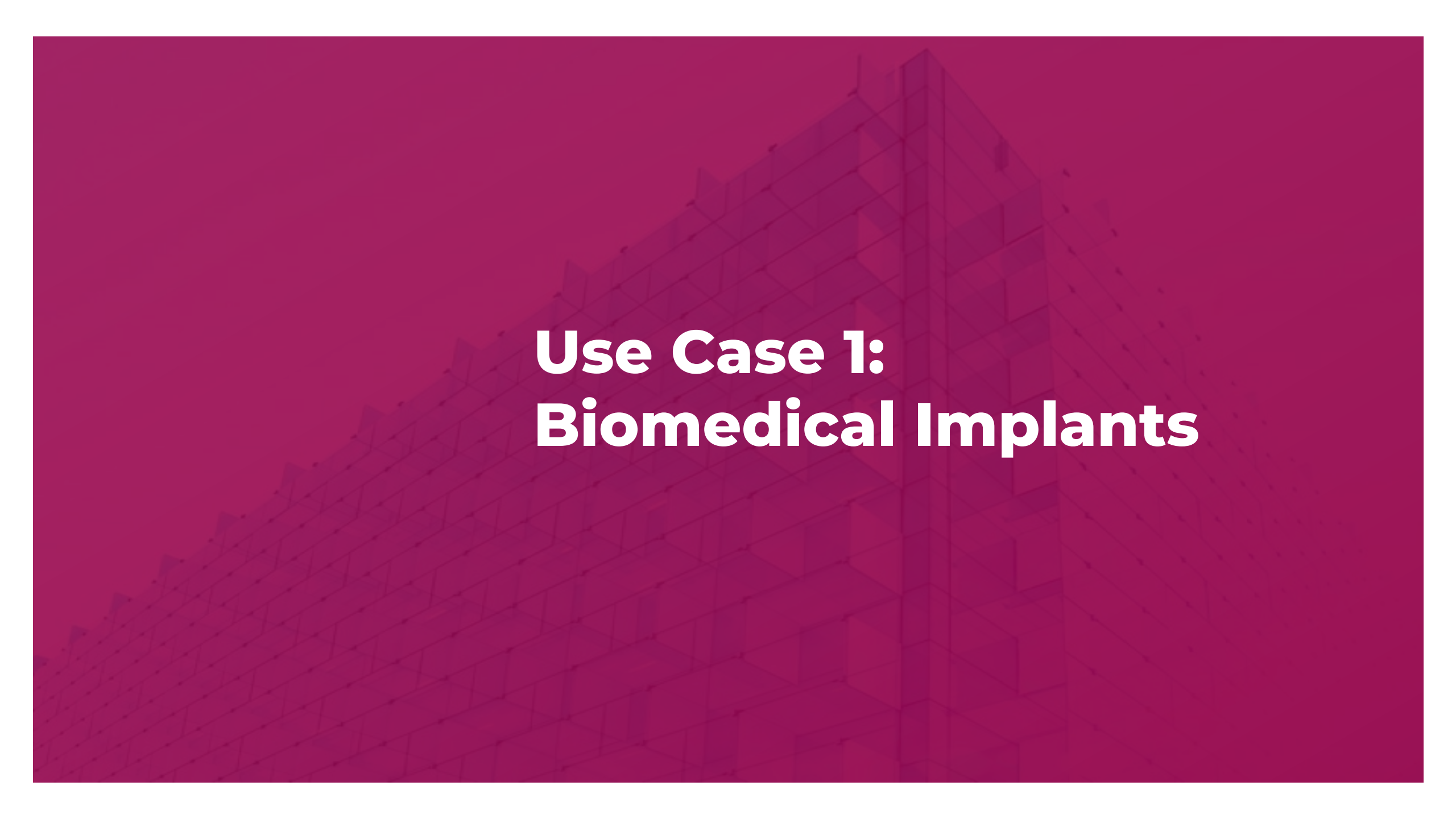
Success Factors vs Limitations of LIPSS





GOOD NEWS!!

OPPORTUNITIES FOR LIPSS APPLICATION
IN INDUSTRIAL ENVIRONMENTS

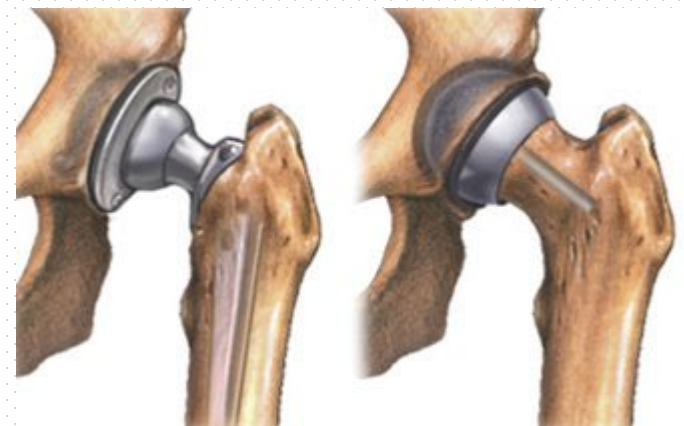
The background is a solid dark red color. Overlaid on this is a faint, light red geometric pattern. This pattern consists of a grid of lines that form a series of overlapping cubes or rectangular prisms, creating a three-dimensional effect. The lines are thin and spaced evenly, creating a mesh-like structure that recedes into the distance.

Use Case 1: Biomedical Implants

Use Case: Biomedical Implants

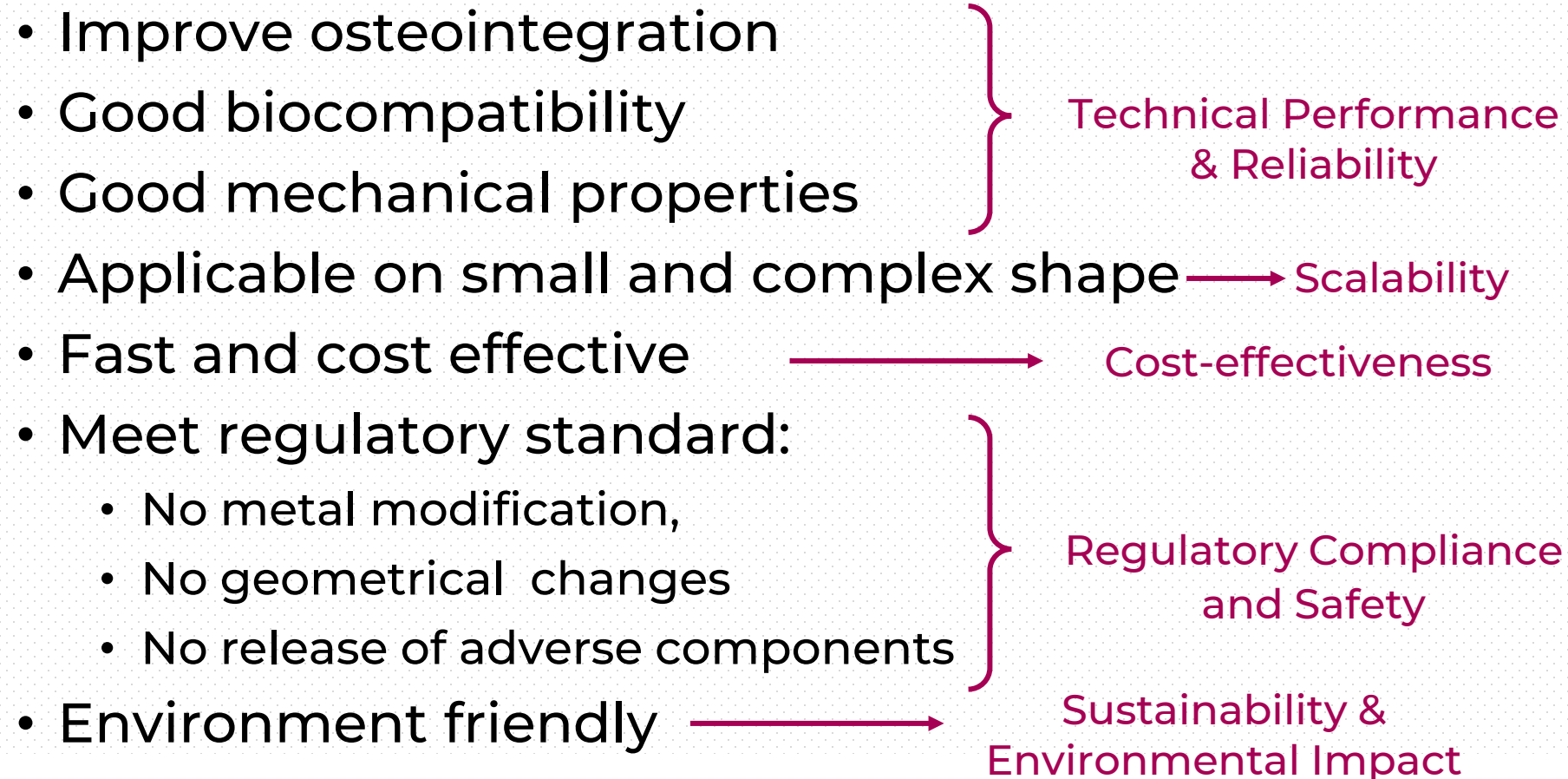
- Most of the times present some metallic components
- Metals have less biocompatibility than polymers but better mechanical properties
- Infections, aging effects and lack of osseointegration can lead to implant failure or rejection

Market Demand



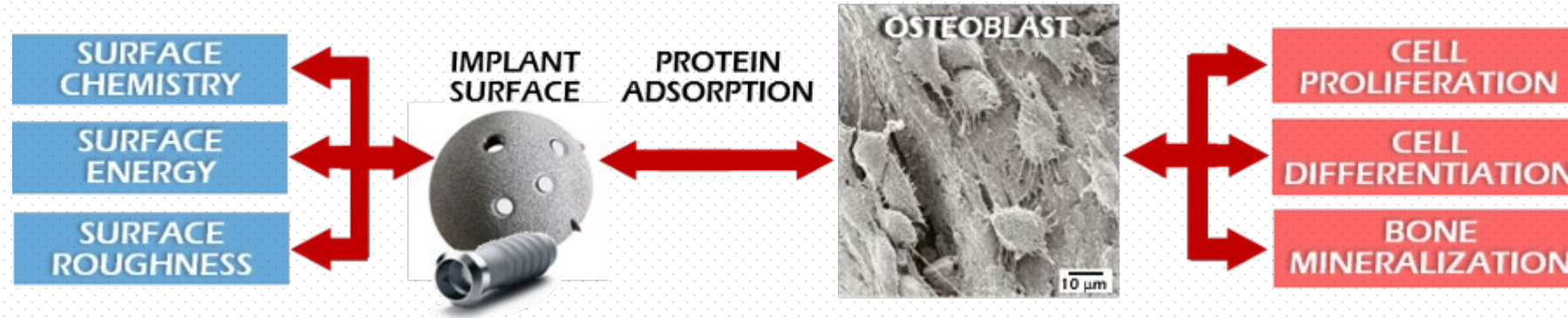
Biomedical Implants

- The expected technical specifications for Laser textured implants are:



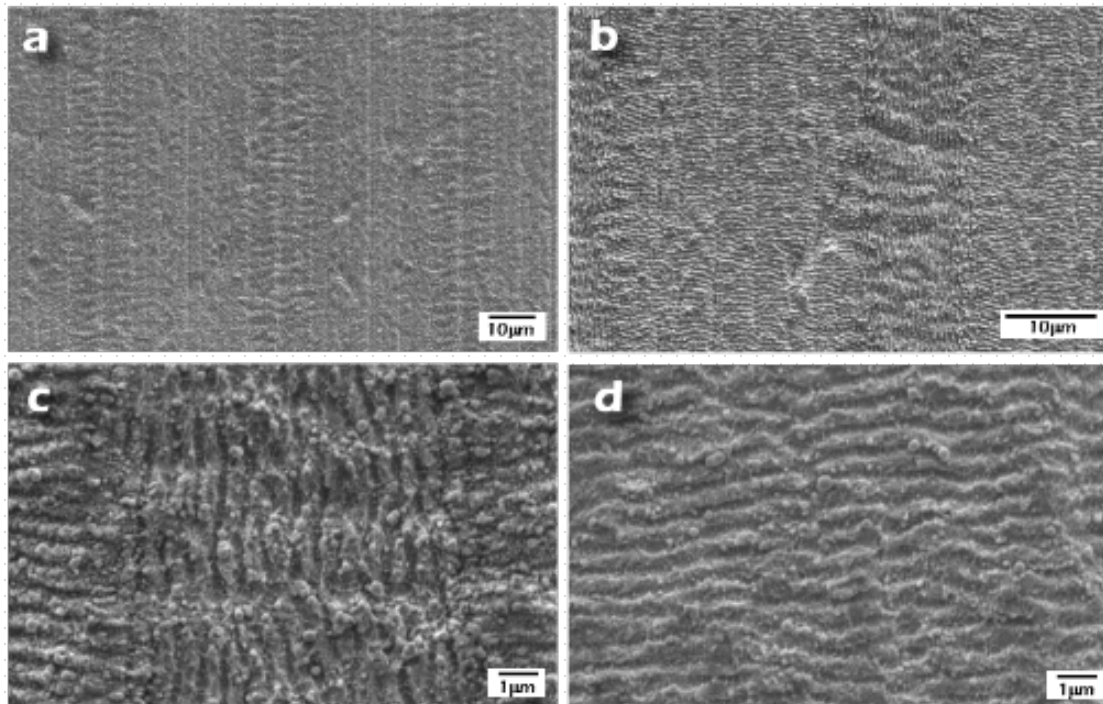
Biomedical Implants – Technical performance

- How can textures improve technical performance?

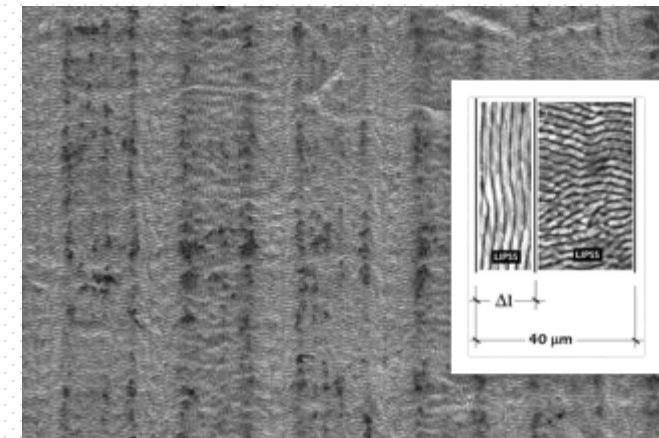
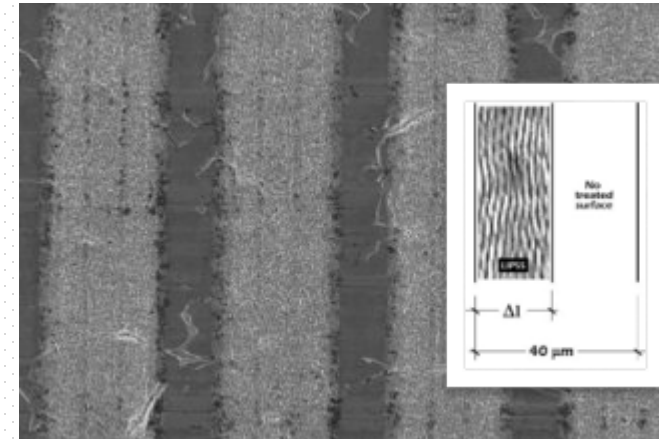


Biomedical Implants – Technical performance

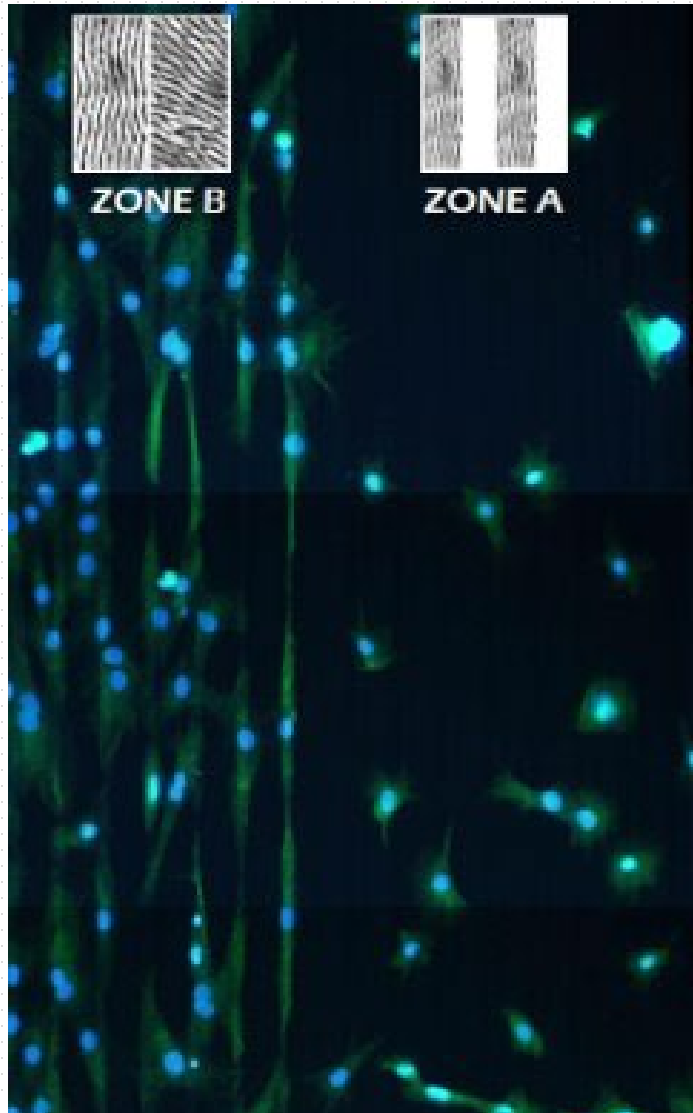
- How can textures improve technical performance?



Low Spatial
Frequency LIPSS
 $\Lambda \sim 580 \text{ nm}$
 $h \sim 150 \text{ nm}$



Biomedical Implants – Technical performance



	Cell density d_c (cm ⁻²)	Cell area A_c (mm ²)	Cell asymmetry AS_c	Polarization P_c
Zone A	$(1,1 \pm 0,5) \times 10^4$	3600 ± 800	7 ± 3	6 ± 3
Zone B	$(2,6 \pm 0,5) \times 10^4$	1900 ± 700	2 ± 1	0 ± 1

Cell asymmetry and polarization much higher in zone A

Cells per unit area much larger in zone B

Promising results regarding controlled cell migration

Ability of attracting and directing this type of cells

Biomedical Implants – Technical performance

- Mechanical behaviour

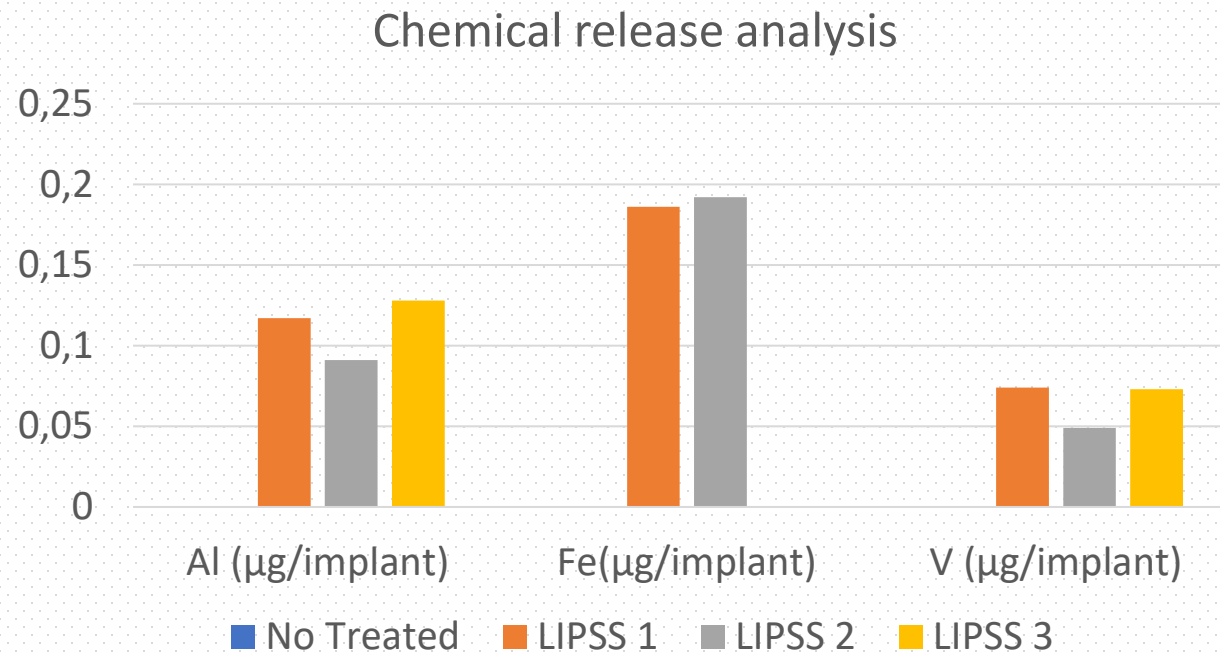
- The screw is held perpendicularly, to the top of a Polyurethane foam block.
- A torsional force is applied on the screw with an axial load to determine the maximum torque reached during the initial four revolutions.
- Then, the rotation is reversed to measure the removal torque.



Customer reference	Maximum insertion torque (N.m)	Maximum removal torque (N.m)
LIPSS 1	0.64+/-0.04	0.51+/-0.04
LIPSS 2	0.72 +/-0.07	0.52+/-0.26
LIPSS 3	0.63+/-0.03	0.51+/-0.05
No treatment	0.67+/-0.06	0.57+/-0.03

Biomedical Implants – Regulatory standards

- No metal modification
- No geometrical changes
- No release of adverse components



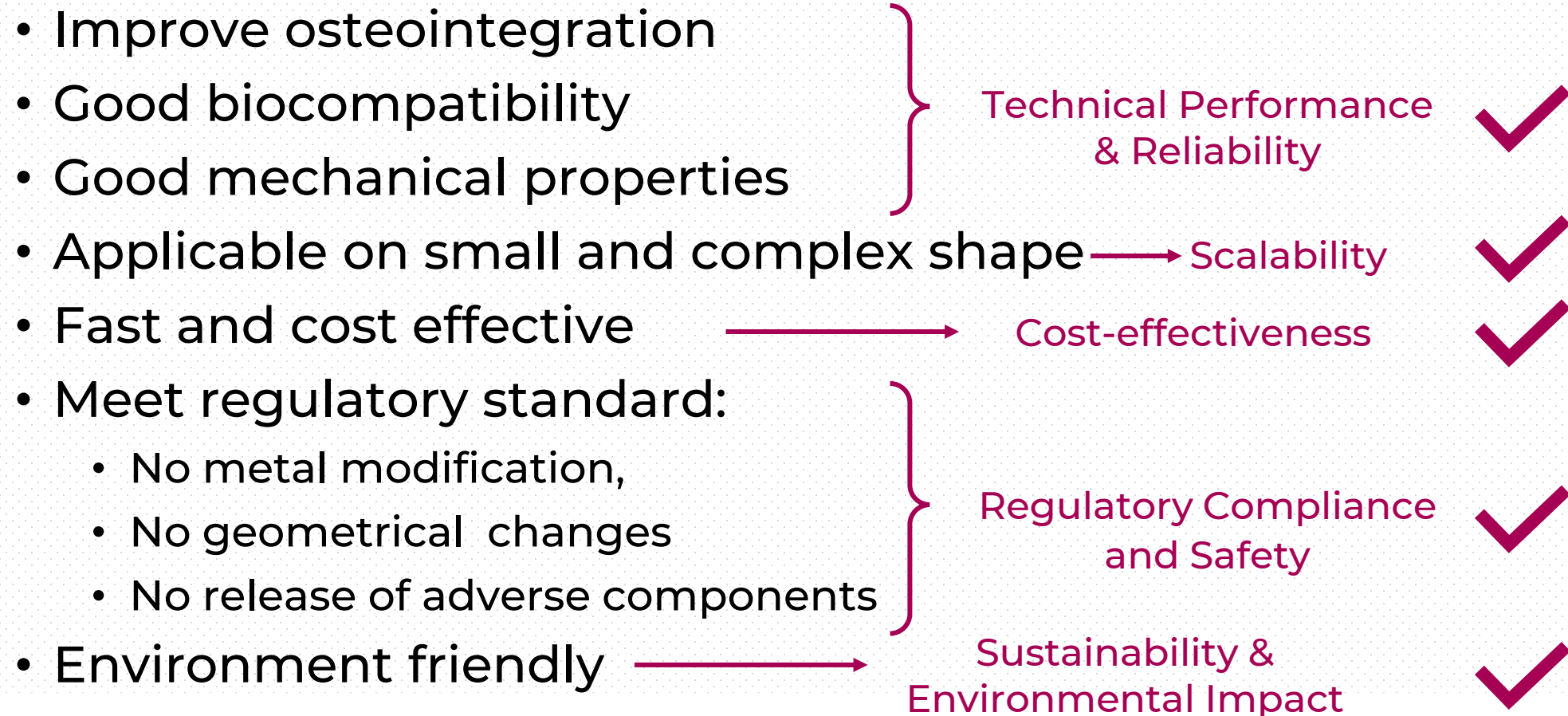
The maximum acceptable threshold calculated according to the ISO 10993-18 (2020) is 0.6µg/implant



All the values are below the maximum acceptable limit

Biomedical Implants

- The expected technical specifications for Laser textured implants are:

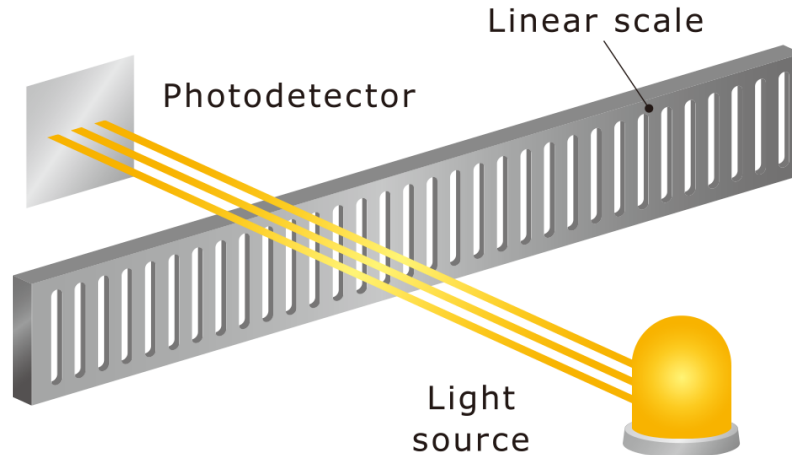


The background of the slide features a maroon color with a faint, isometric pattern of overlapping cubes or a diffraction grating structure, creating a sense of depth and geometric complexity.

Use Case 2: Diffraction Gratings

Use Case: Diffraction Gratings for Metrology Applications

- Optical encoders for metrology applications are based on very precise scales
 - Resolution of encoders is directly related to the scale period
- Standard manufacturing methods are based on photolithographic processes



Optical linear encoder (Transmissive type)

Use Case: Diffraction Gratings for Metrology Applications

- The expected technical specifications of LIPSS based scales are:
 - Improved performance
 - Increased resolution
 - Enhanced detected electrical signal
 - Precision and accuracy of periodic lines
 - Environmentally friendly manufacturing process
 - Cost-effective process

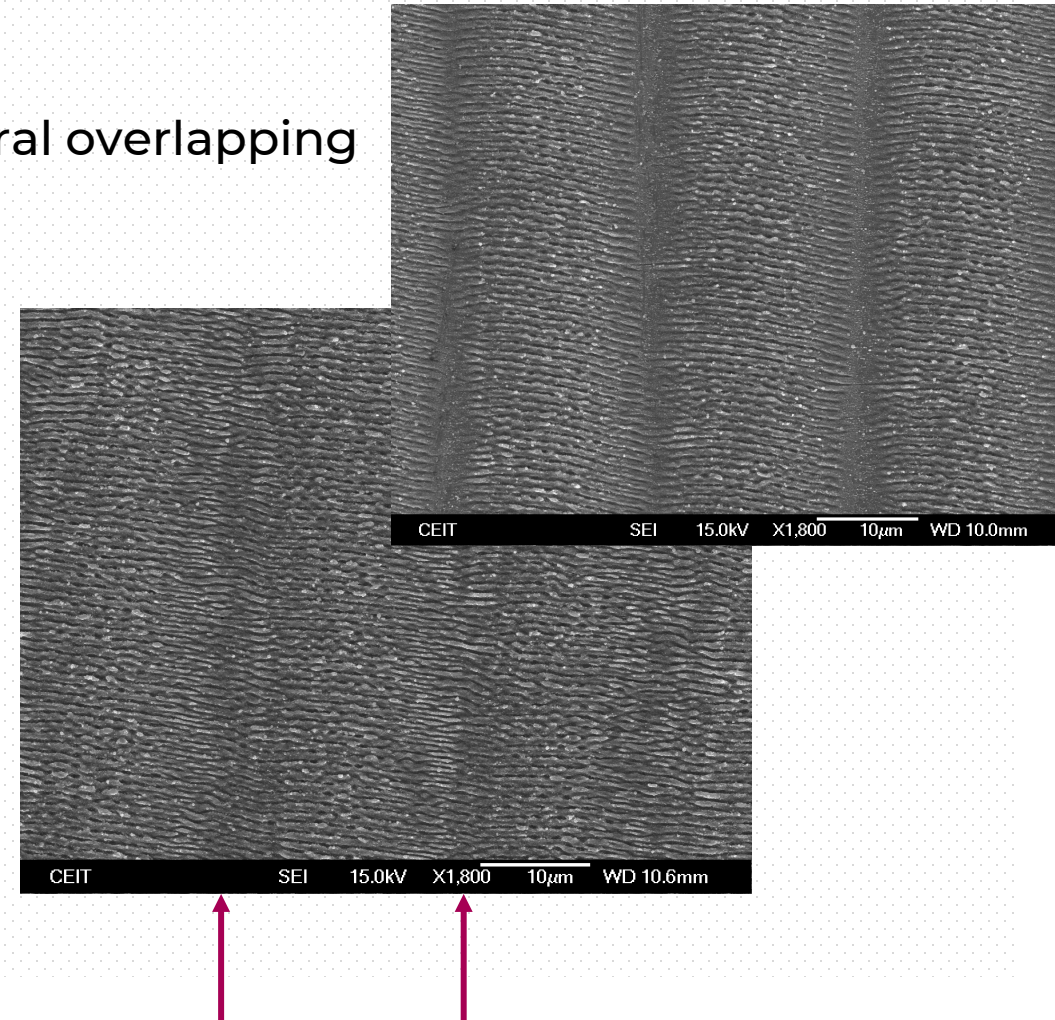
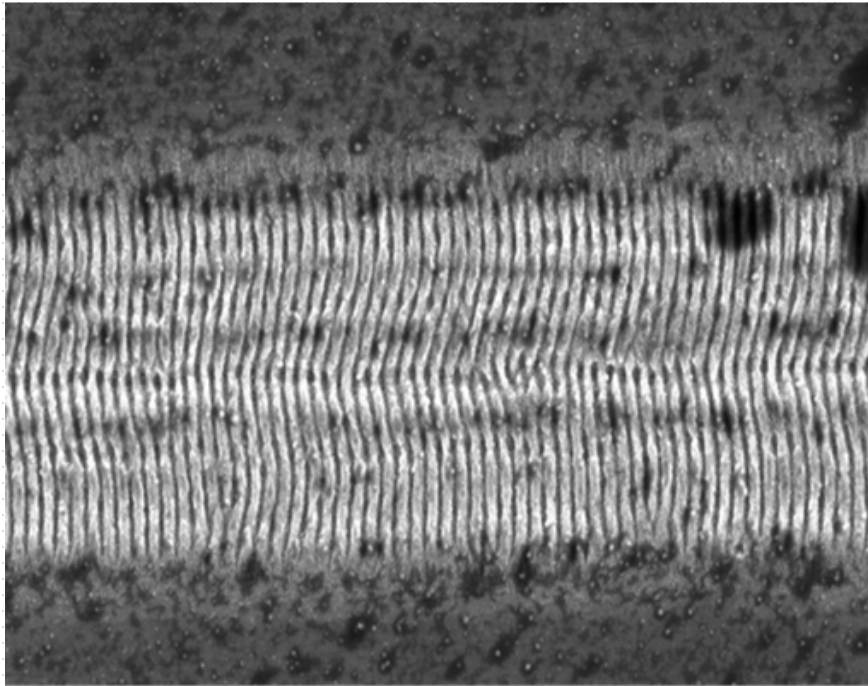
Use Case: Diffraction Gratings for Metrology Applications

- Environmentally friendly manufacturing process & Cost-effectiveness
 - Laser processing completely eliminates chemicals from the manufacturing process:
 - Photoresists
 - Cr layers
 - Developer, acetone, ethanol...
 - Operational costs of lithographic equipment and processes are quite high

*Industrial viability mainly depends on
the technical performance of LIPSS
based scales*

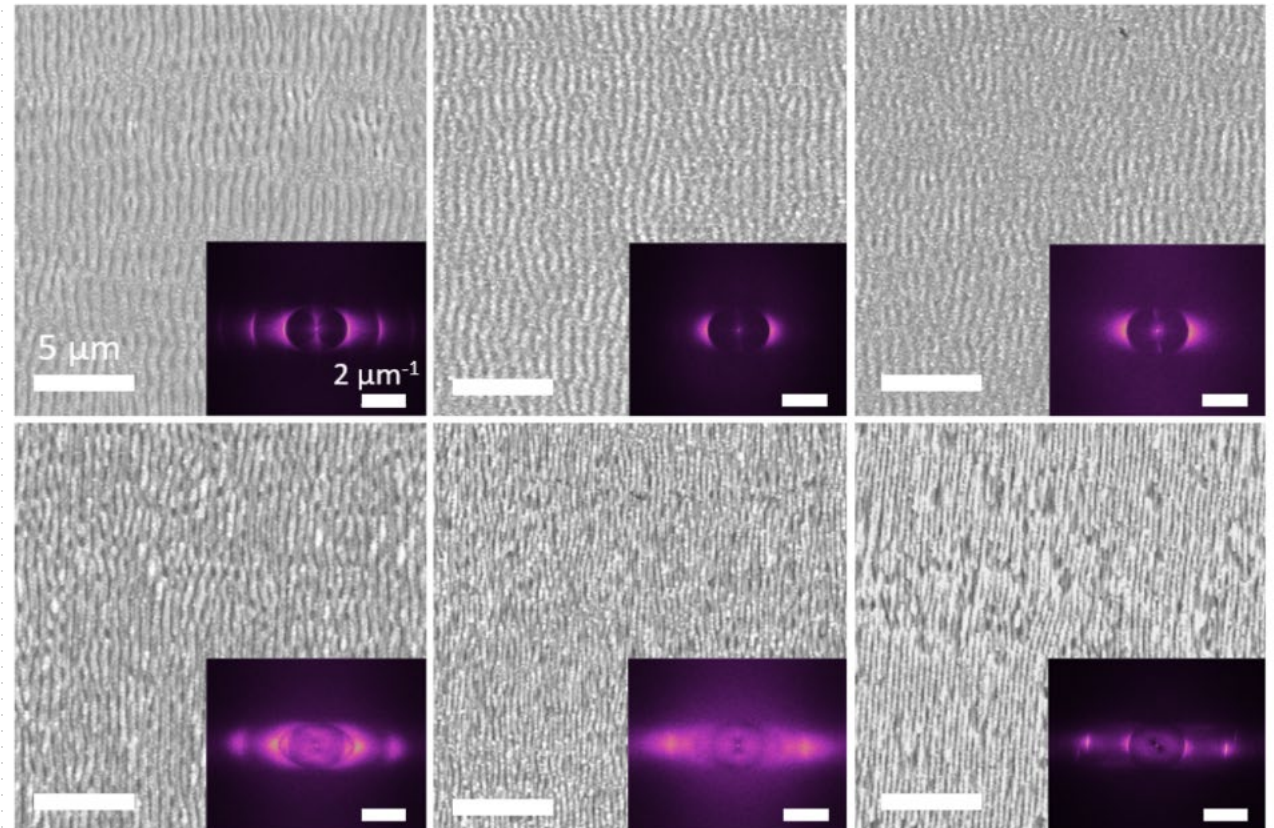
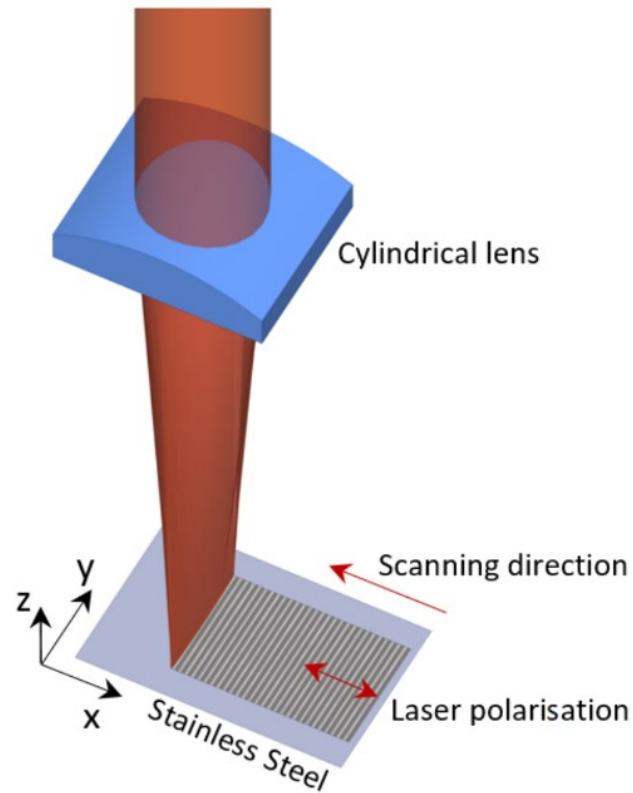
Diffraction Gratings - Requirements

- Very precise and regular periodic lines are required:
 - Poor homogeneity
 - Discontinuities corresponding to Hatch or lateral overlapping



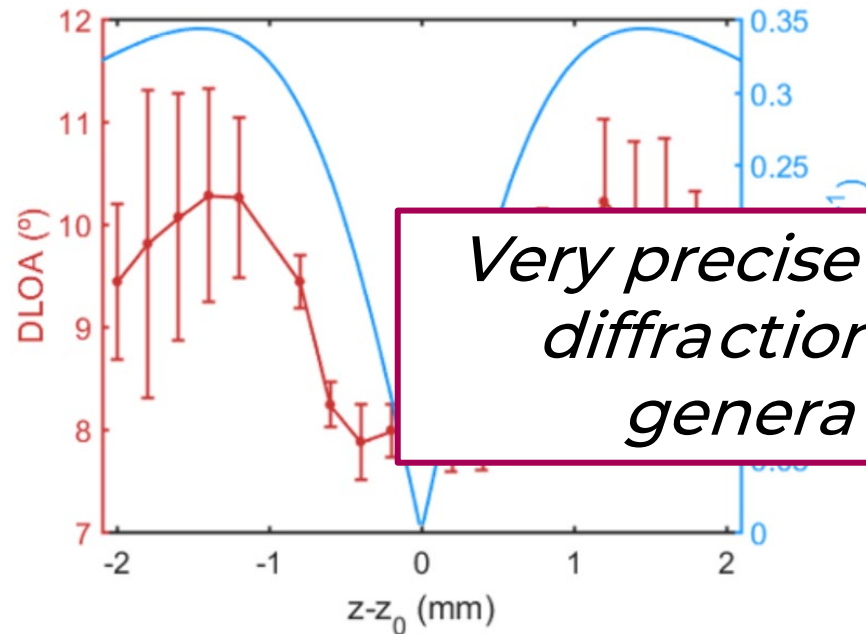
Diffraction Gratings – Homogeneity optimization

- 1st step: avoid overlapping → cylindrical lens



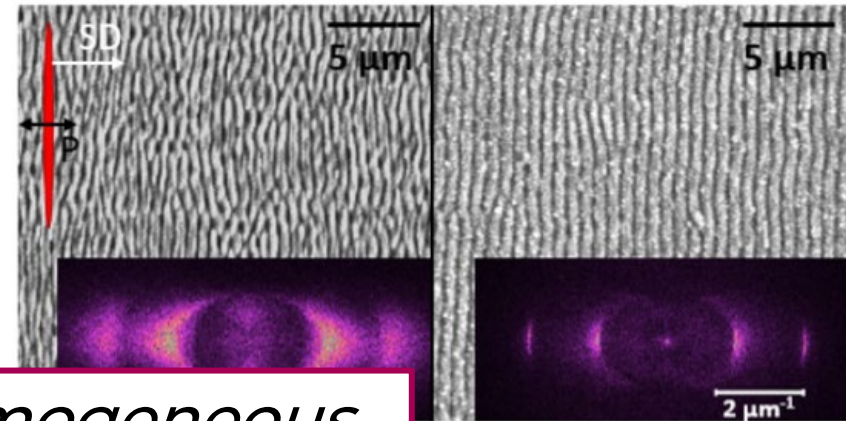
Diffraction Gratings – Homogeneity optimization

- 2nd step: improve homogeneity

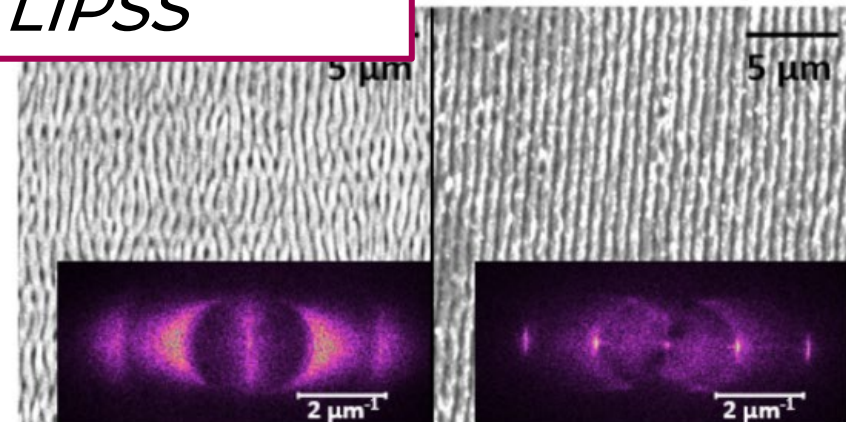


Very precise and homogeneous diffraction gratings can be generated with LIPSS

a) $w_x=55 \mu\text{m}$, $v=1 \text{ mm/s}$, $E=1.4 \text{ mJ}$
 $f=50 \text{ mm}$, $z-z_0=0.6 \text{ mm}$ $f=100 \text{ mm}$, $z-z_0=0.2 \text{ mm}$



$v=0.6 \text{ mm/s}$, $E=0.8 \text{ mJ}$
 $f=75 \text{ mm}$, $z-z_0=0$



Conclusions

- LIPSS can be successfully used for industrial applications
- Success factors do not rely only in technical performance
 - Market demand
 - Application suitability
 - ...
 - and many more become determinant.

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Thank you,
muchas gracias,
eskerrik asko



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