Enhancement of the bioactivity of titanium surfaces by combining laser texturing and calcium phosphate deposition

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INTRODUCTION

Titanium in Implantology

- Mechanical strength, fatigue resistance, and low elastic modulus
- Corrosion resistance - stable native TiO_2 oxide layer
- Biocompatibility well established in both in vitro and in vivo models
- Biologically inert surface limits osseointegration
- Osseointegration governed by surface physicochemical and topographical properties, regulating protein adsorption and osteogenic cell response

Laser Surface Texturing (LST)

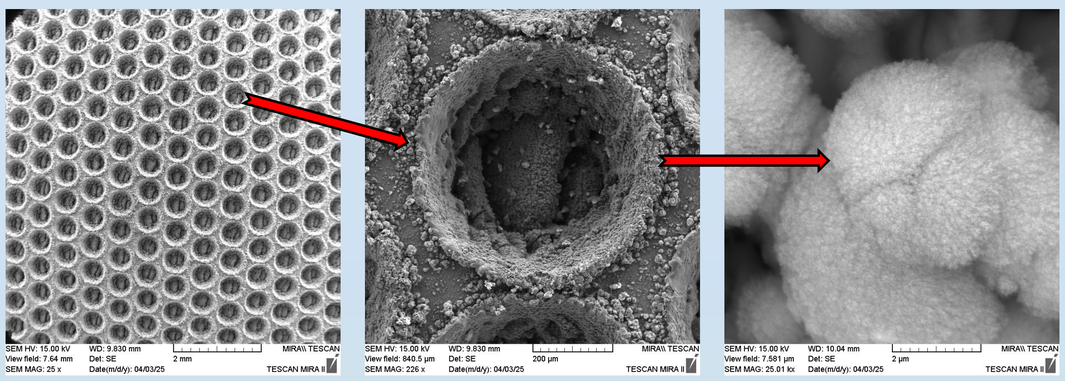
- Ultrashort-pulse laser systems: precise, reproducible surface modification
- Generation of laser-induced periodic surface structures
- Mimics natural architecture at micro- and nano-scale
- Promotes osteoblast adhesion, contact guidance, and proliferation
- Activates mechanotransduction pathways upregulating osteoblastic gene expression

Calcium Phosphate Deposition

- Replicates the mineral phase of native bone tissue
- Facilitates precipitation of biological apatite from physiological fluids
- Stimulates osteoblast differentiation and accelerates bone matrix mineralization
- Improves implant bioactivity through direct chemical bonding with host bone tissue
- Coating adhesion strength critically dependent on underlying surface topography

EXPERIMENTAL

Titanium laser texturing

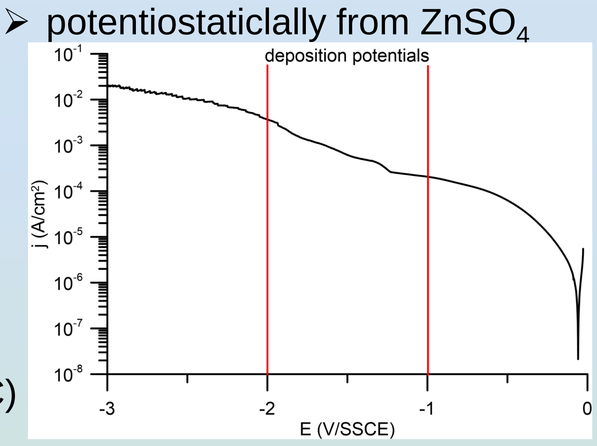


Simulated body fluid (SBF)

chemical formula	concentration ($mmol \cdot l^{-1}$)
NaCl	142.0
$NaHCO_3$	4.2
KCl	5.0
K_2HPO_4	1.0
$MgCl_2 \cdot 6H_2O$	1.5
$CaCl_2$	2.5
Na_2SO_4	0.5
Tris buffer	50.0

Calcium phosphate deposition

- potentiostatic polarisation in SBF
- zinc incorporation by second deposiotion
- potentiostaticlally from $ZnSO_4$



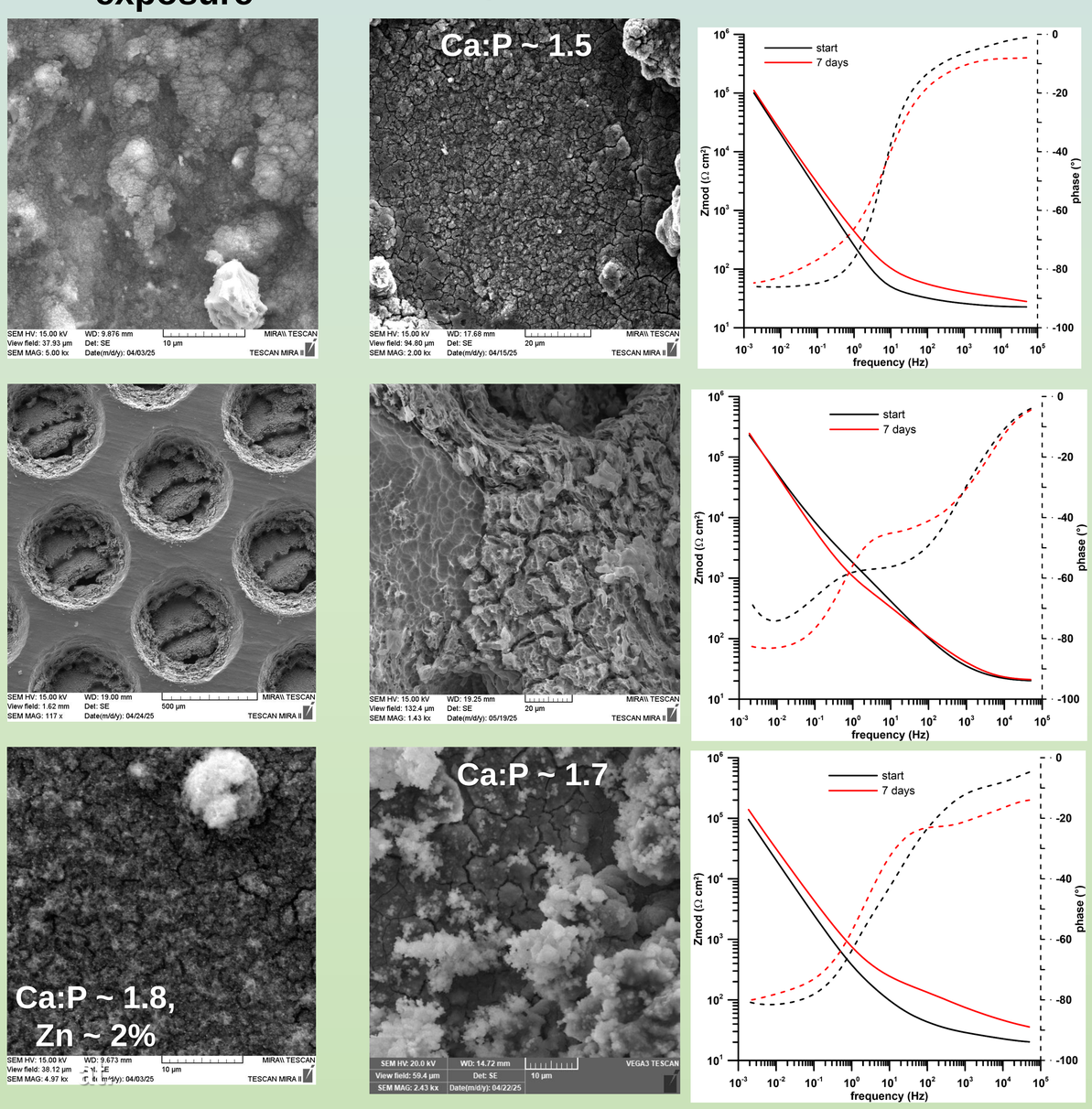
Bioactivity testing - exposure in SBF

*7 days in SBF

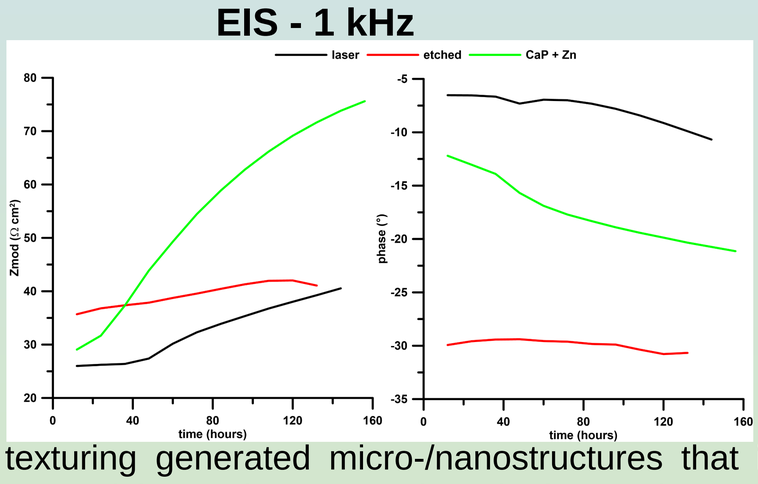
* laser, laser + CaP, etched laser

*EIS monitoring (50 kHz- 2 mHz, 10 mV AC)

RESULTS



EIS - 1 kHz



- Laser texturing generated micro-/nanostructures that improved surface reactivity and supported early interactions with SBF, although the extent of apatite formation after 7 days remained limited.
- Etching of the laser-textured surface suppressed CaP precipitation entirely, indicating that the chemical/morphological alterations removed key nucleation sites created by laser processing.
- CaP + Zn coating exhibited higher initial bioactivity, confirmed by Ca:P ratios (~1.7–1.8) and Zn incorporation (~2 at.%).
- EIS showed gradual impedance growth for the laser surface, reflecting slower apatite development, whereas CaP + Zn samples showed high initial impedance and a much earlier mineralization response.
- Overall, nanotopography improved baseline bioactivity, but the fastest and most stable mineralization occurred when laser structuring was combined with the CaP + Zn layer.
- Zinc incorporation (~2 at.%) further modified the coating chemistry and may contribute to enhanced osteogenic response, providing an additional functional benefit not achievable by topography or CaP alone.

CONCLUSION

The results show that laser-induced micro- and nanotopography enhances the intrinsic bioactivity of titanium by promoting ion reactivity and supporting early stages of apatite formation. The etched laser-textured sample, which did not exhibit CaP precipitation, effectively serves as a negative control and confirms that the surface features created by laser processing are essential for nucleation. In contrast, the CaP + Zn coating provides a highly bioactive chemical environment, enabling substantially earlier and more pronounced mineralization as supported by EIS analysis. Overall, the combination of laser-generated topography with a bioactive CaP-based layer represents the most effective approach for achieving rapid and stable surface mineralization of titanium implants

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