Electrochemistry Group

Functionalization of hard tissue implants surface by plasma electrooxidation

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17-19.10.2018, Sumy, Ukraine

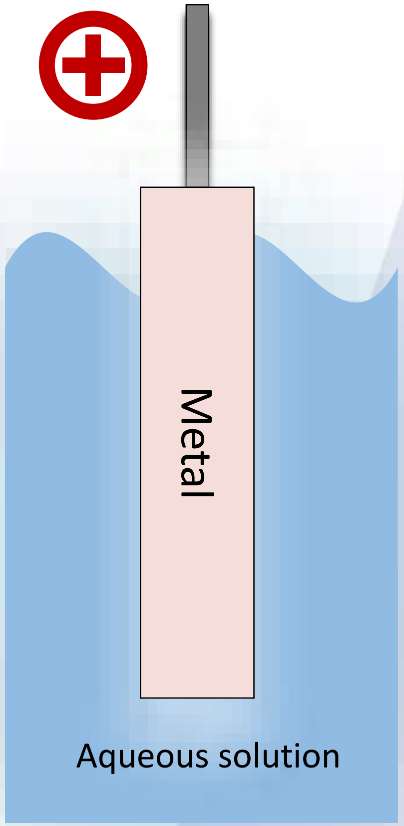
Anodic oxidation

Anodic oxidation of metals and alloys

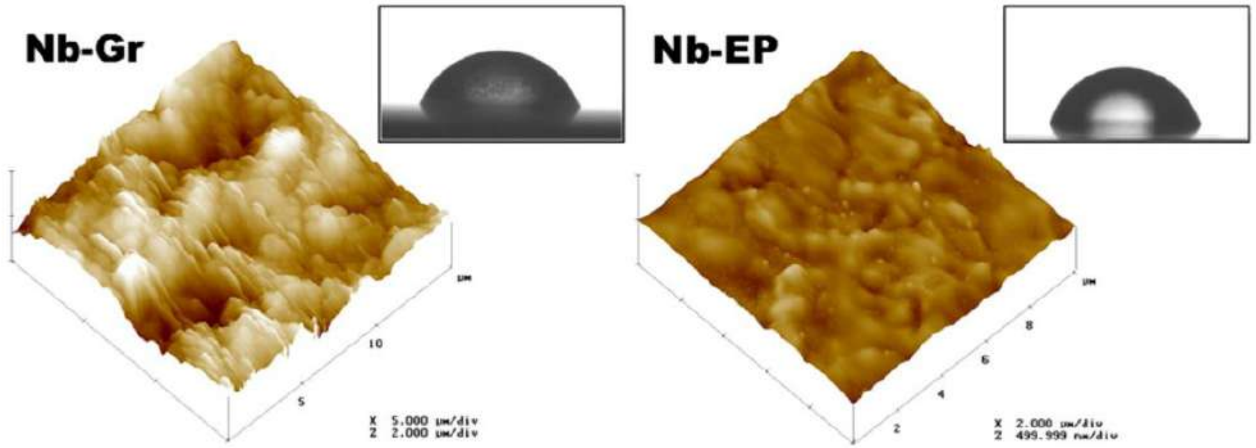
The process is based on **anodic polarisation** of the treated element

As a result of the process is

???

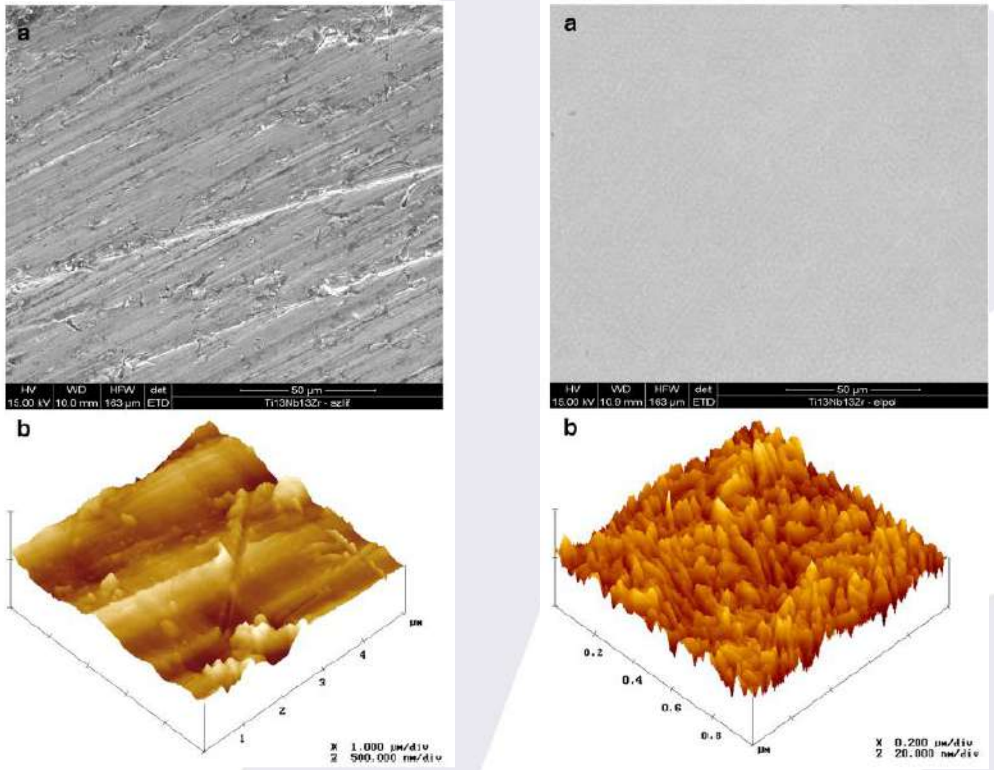


Electropolishing



AFM images of Nb before and after electropolishing

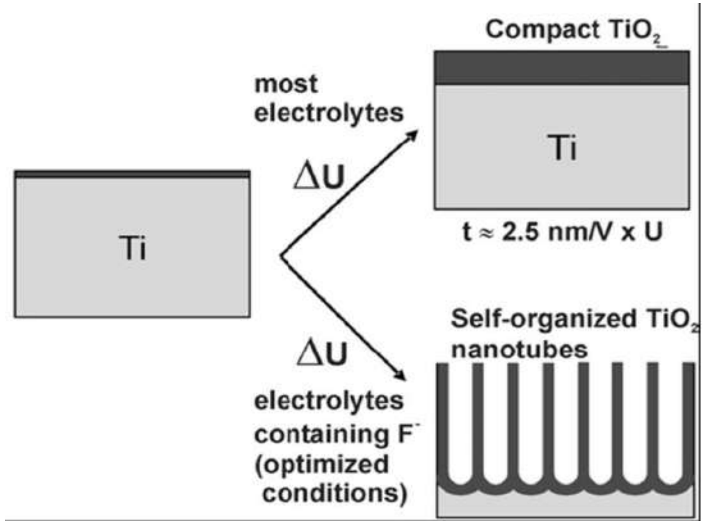
$$Me = Me^{z+} + ze^{-}$$

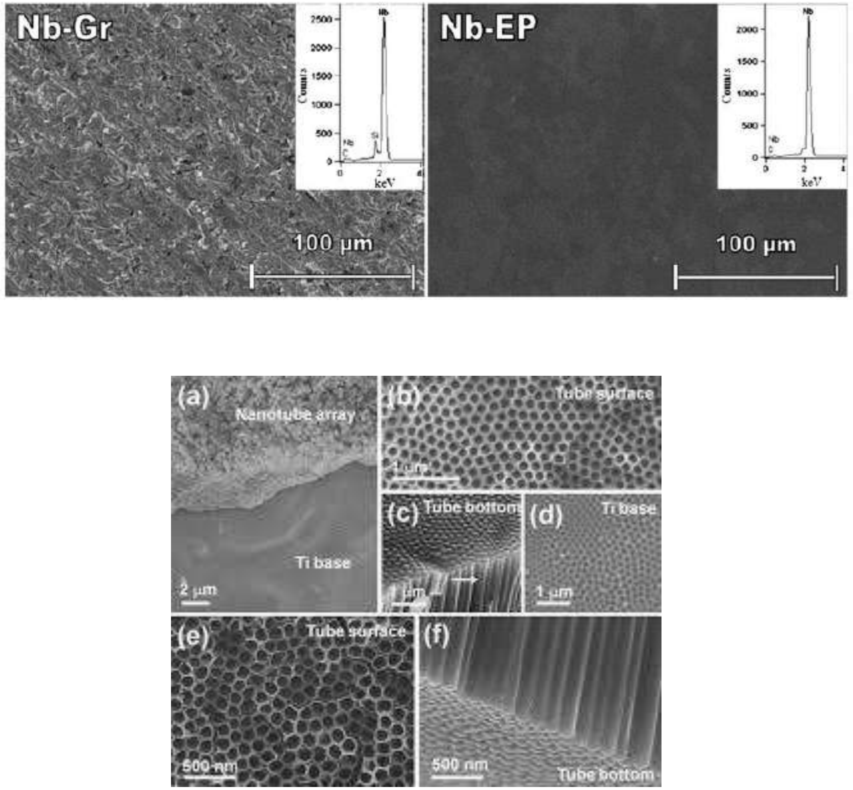


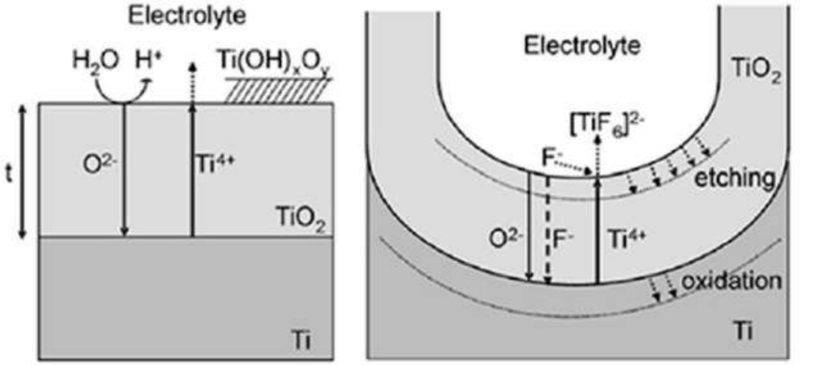
SEM (a) and AFM (B) images of Ti-13Nb-13Zr alloy before and after electropolishing

M. Sowa et al. / Materials Science and Engineering C 42 (2014) 529–537 / W. Simka et al. / Surface & Coatings Technology 213 (2012) 239–246

Anodic oxidation



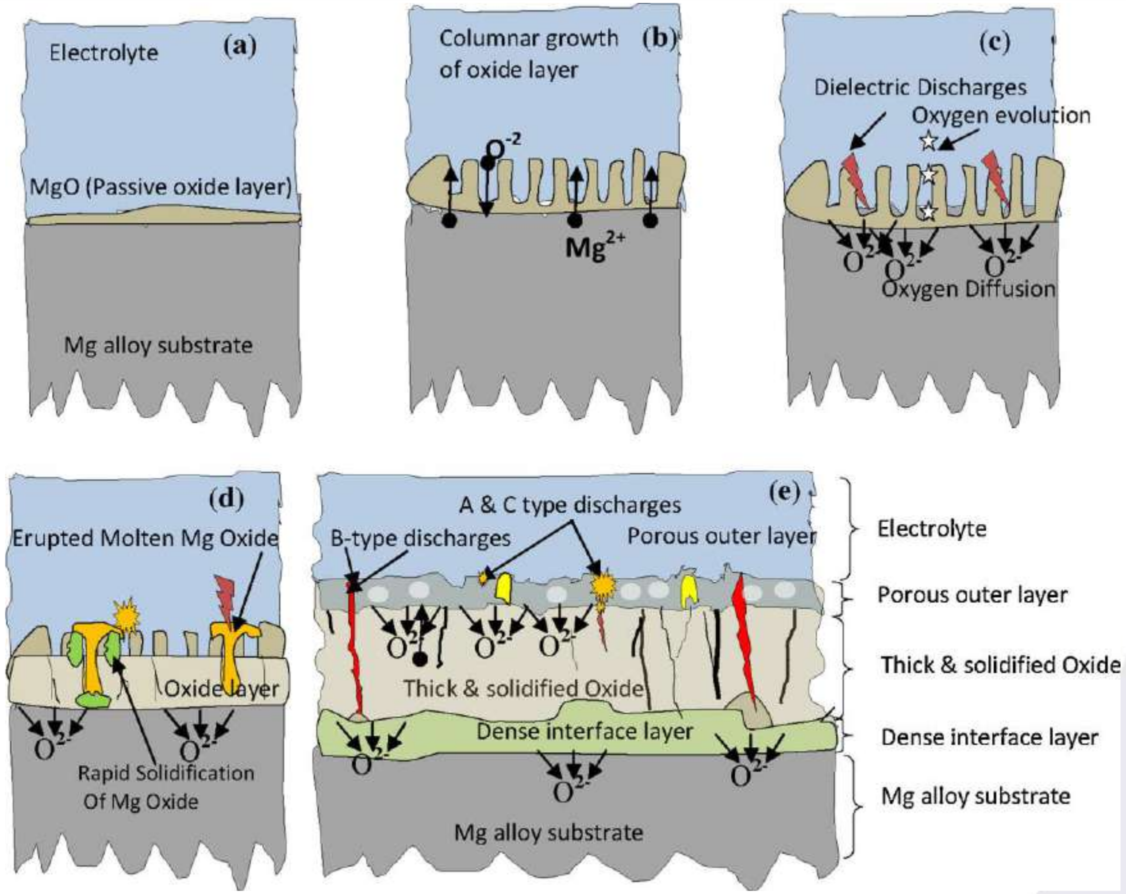




Macak JM, Tsuchiya H, Ghicov A, Yasuda K, Hahn R, Bauer S, *et al*. TiO_2 nanotubes: Self-organized electrochemical formation, properties and applications. Current Opinion in Solid State and Materials Science. 2007;11(1-2):3-18.

M. Sowa et al. / Materials Science and Engineering C 42 (2014) 529–537

Plasma electrolytic oxidation (PEO)



R.O. Hussein et al. / Electrochimica Acta *112 (2013) 111– 119*

Plasma electrolytic oxidation (PEO)

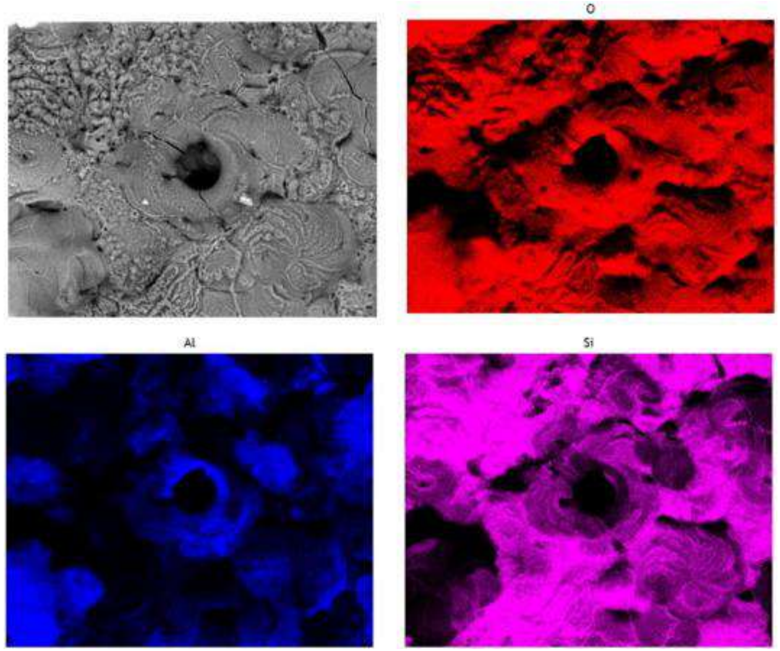
Parameters:
- Voltage
- Current type (AC, DC, pulse)
- Current density
- Electrolyte chemical composition
- Temperature
- Time
- Pretreatment

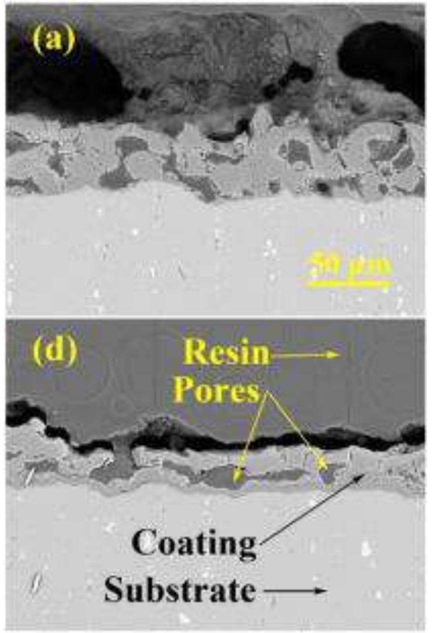
→

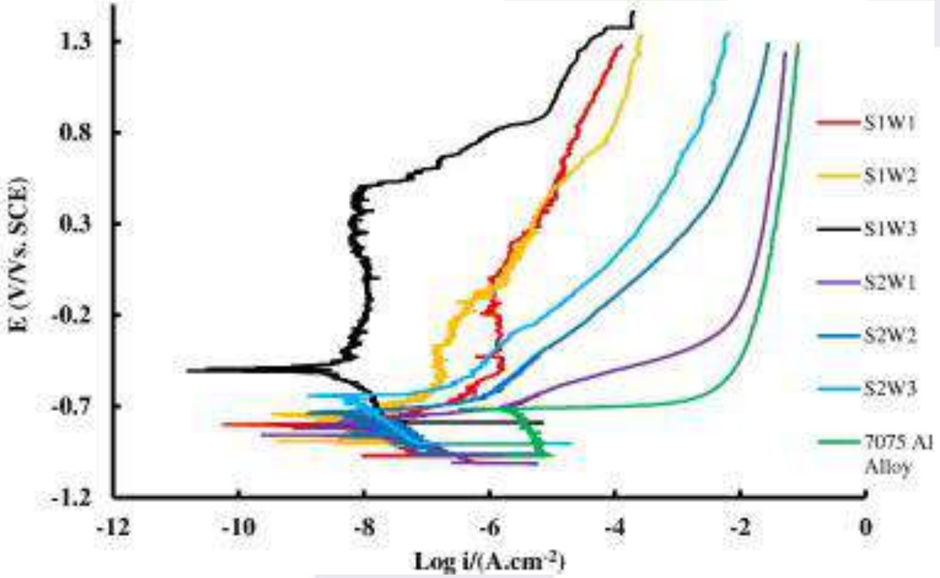
Different results:
- Morphology, topography
- Oxide layer thickness
- Chemical composition of oxide layer
- Mechanical properties
- Corrosion resistance
- Biological properties

Corrosion and wear protection

PEO of Al in silicate solution

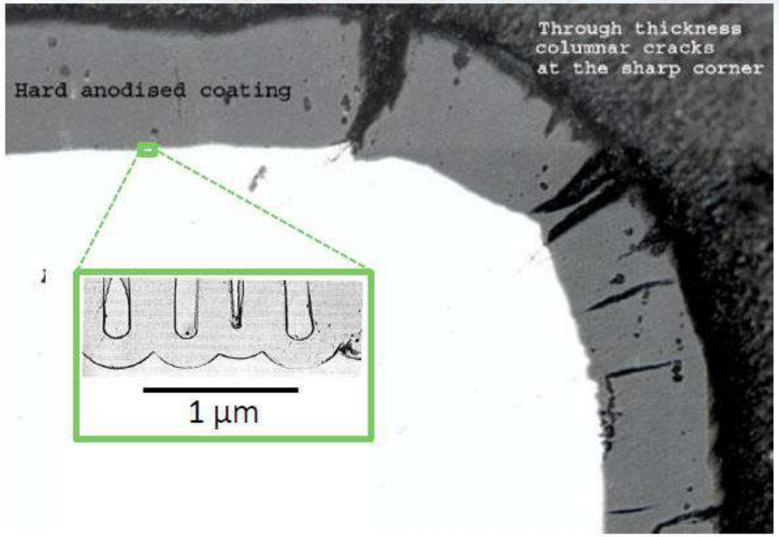


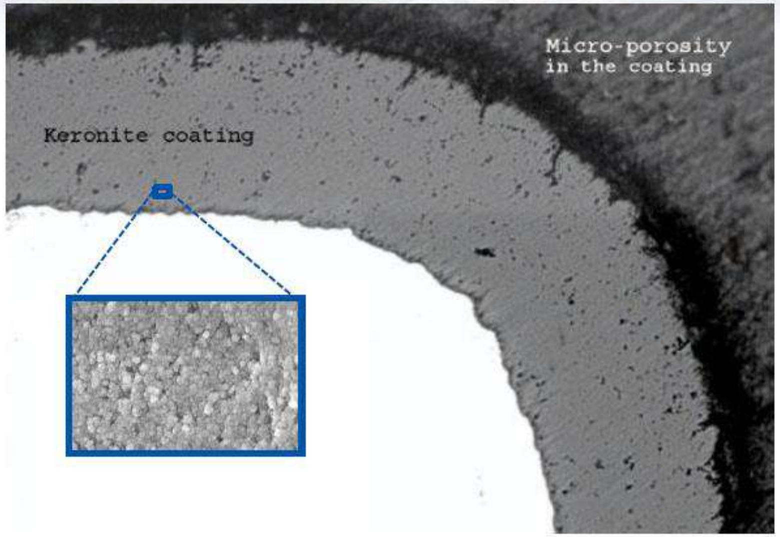




Amin Hakimizad et al. / Surface & Coatings Technology 324 (2017) 208–221

Corrosion and wear protection





KERONITE, UK

Chrome-free Mg corrosion and wear protection

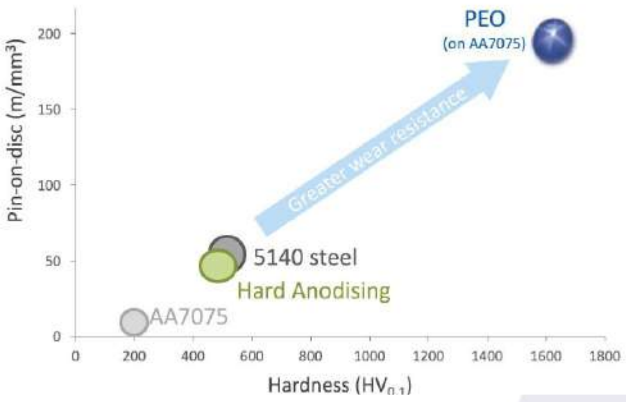
Ti6Al4V wear protection

Aluminium wear protection

Thermal barrier protection,
optical surfaces,
high power dielectric insulation

Similar to anodising: Uniform coverage of complex shapes
Well-controlled, predictable growth

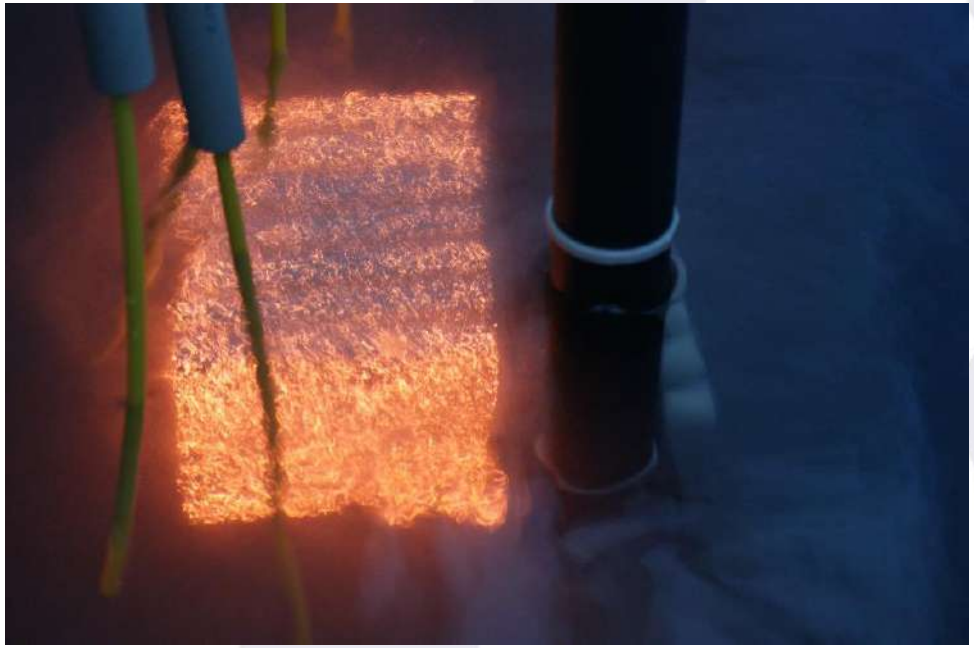
Non-columnar structure: Superior edge protection
Less susceptible to corrosion, wear
Lower fatigue debit



Corrosion and wear protection

Magnesium and aluminium alloys

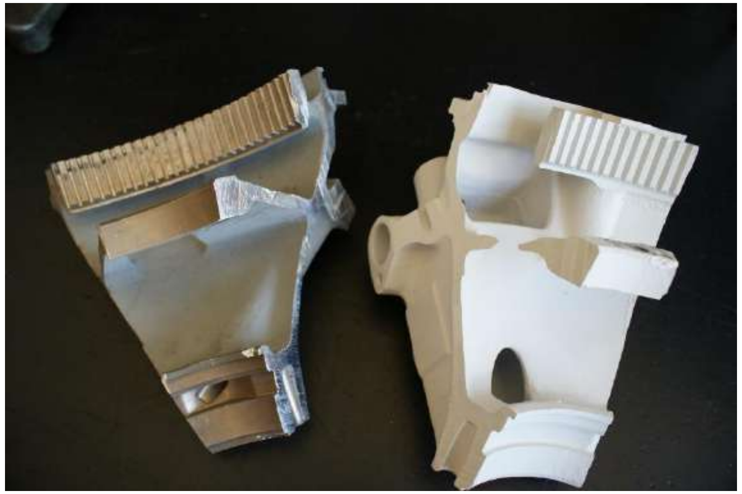
in cooperation with Pratt & Whitney, Rzeszów, Poland / and Rzeszów University of Technology

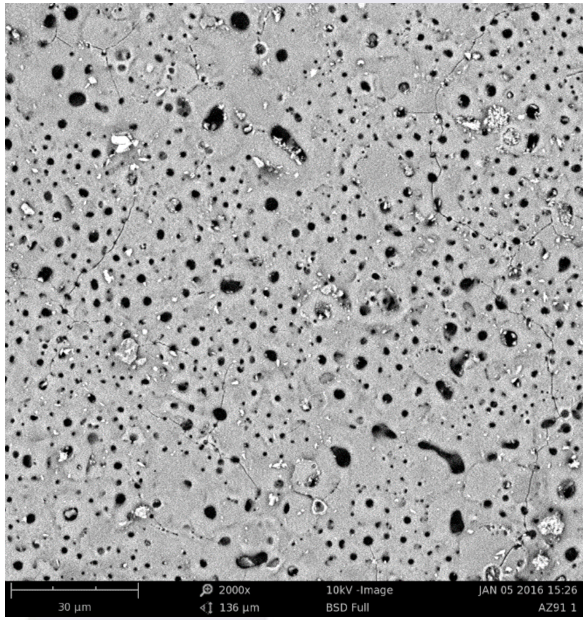


Corrosion and wear protection

Magnesium and aluminium alloys

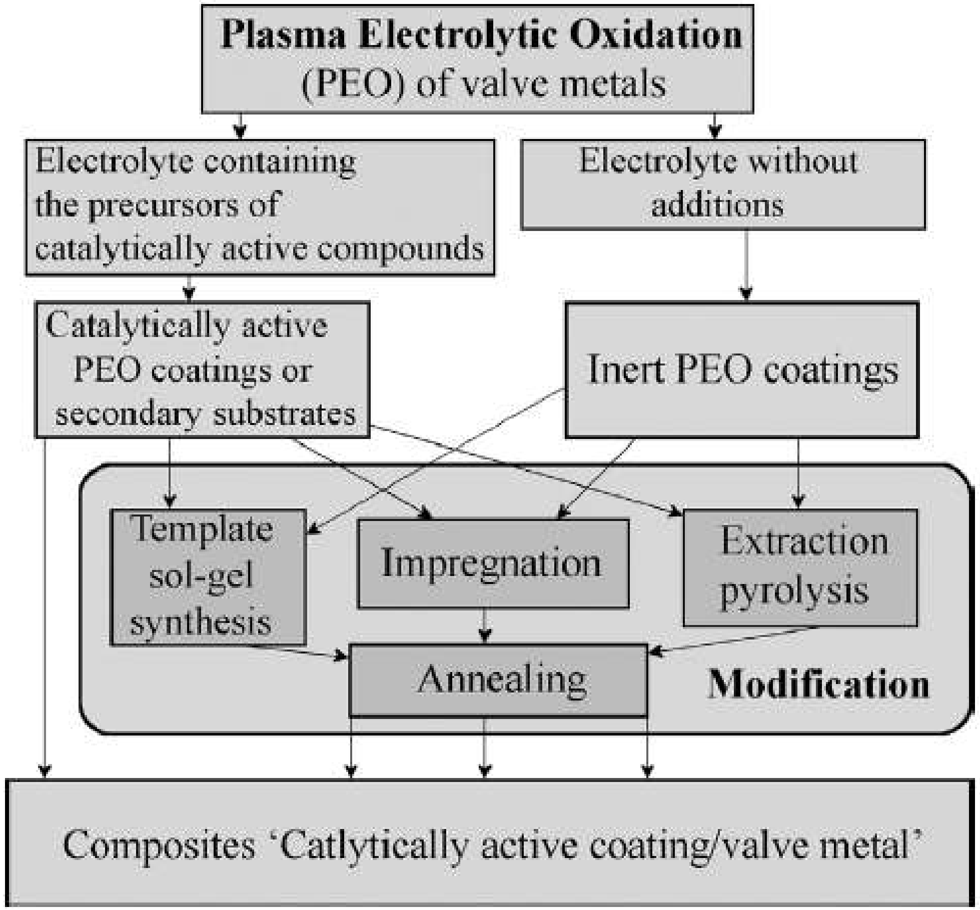
in cooperation with Pratt & Whitney, Rzeszów, Poland / and Rzeszów University of Technology





- ✓ **Improvement of corrosion properties**

Catalysis

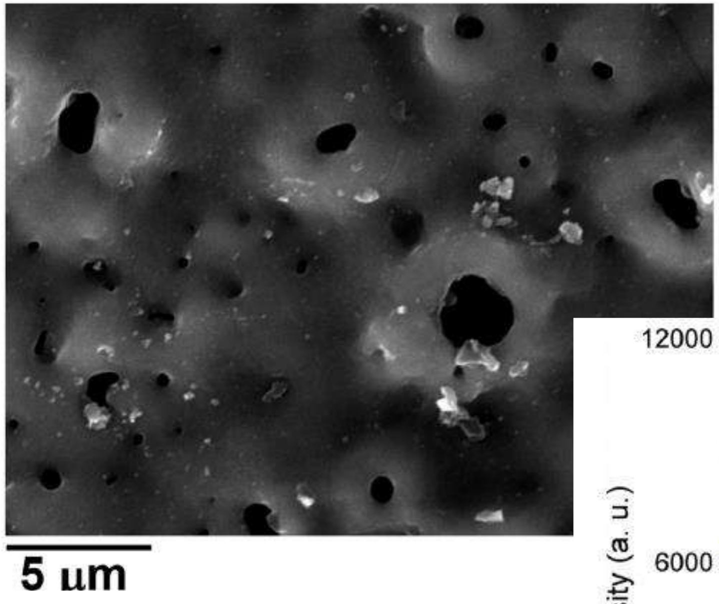


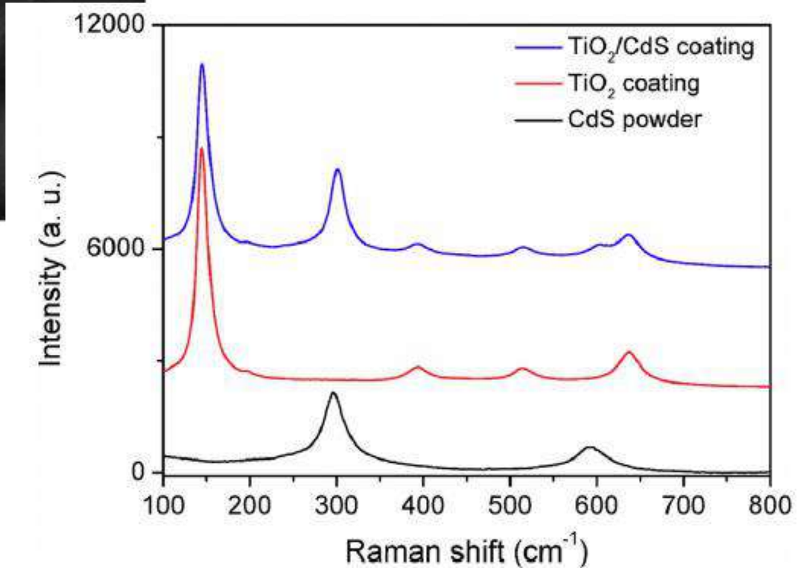
I.V. Lukiyanchuk et al. / Applied Surface Science 315 (2014) 481–489

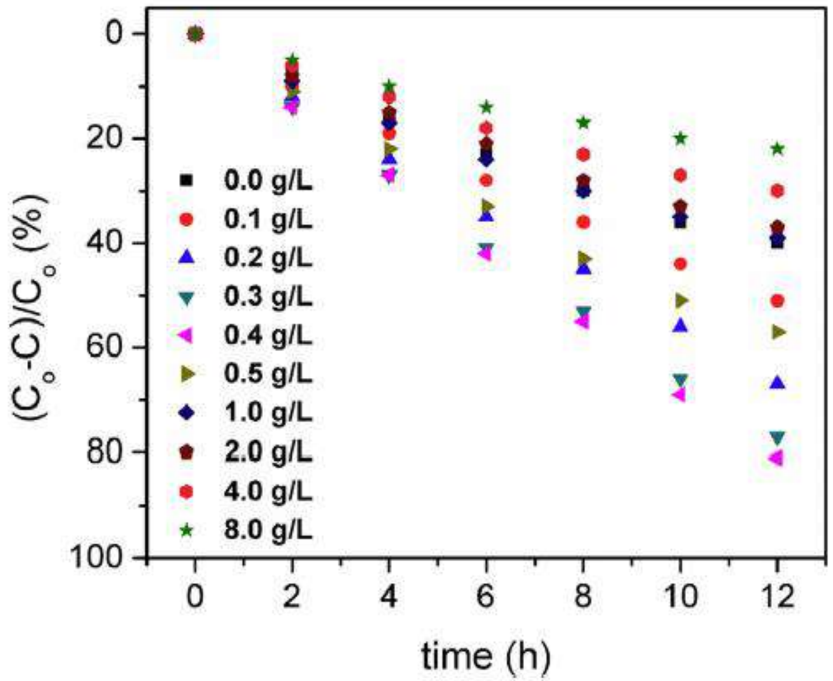
Catalysis

Ti/TiO_2-CdS photocatalyst

The photodegradation of aqueous methyl orange (MO)

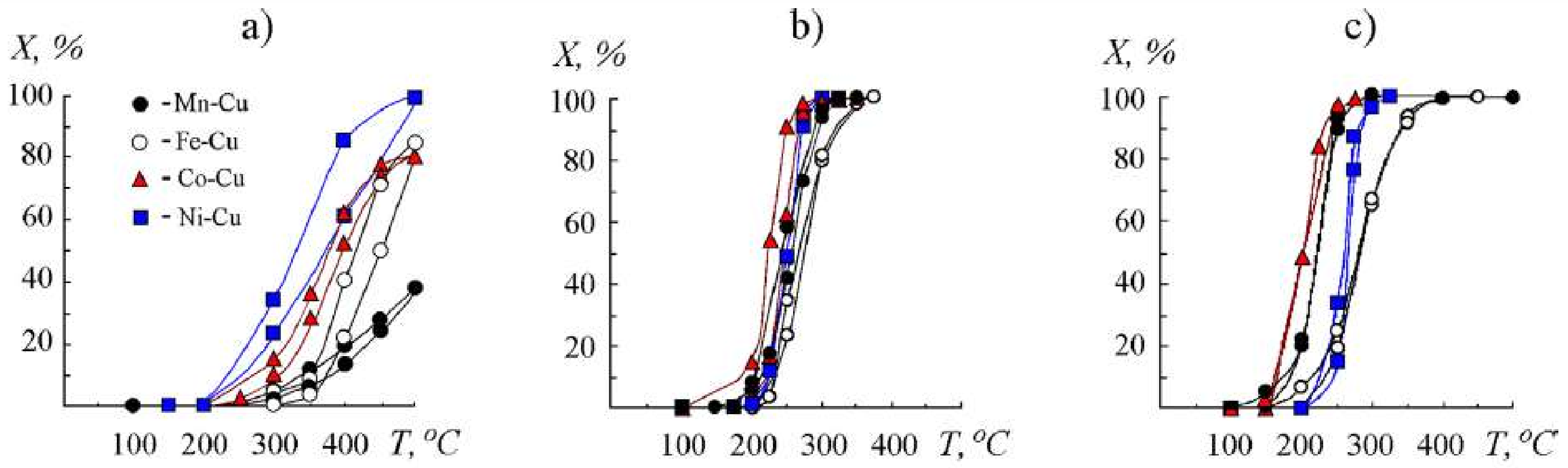




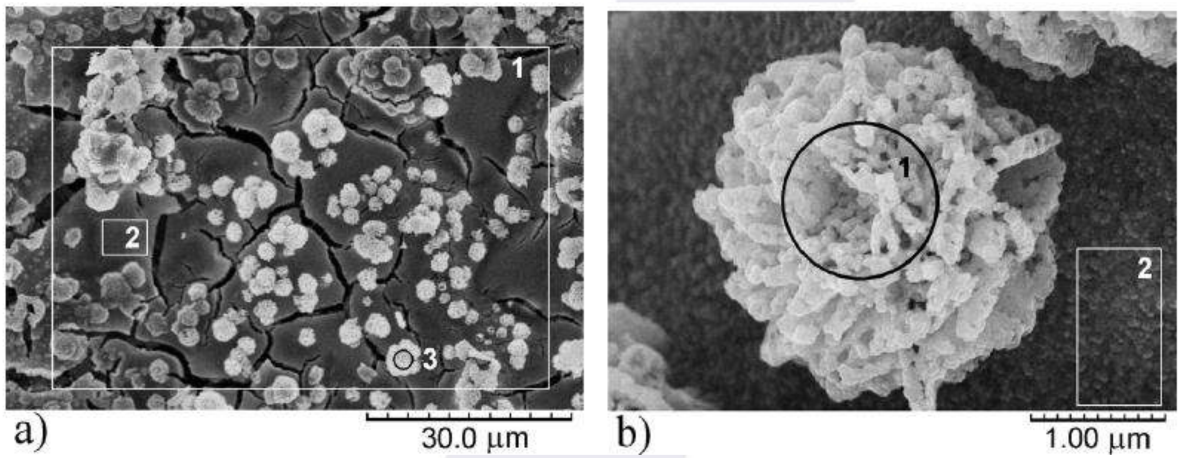


S. Stojadinović, Surface & Coatings Technology 344 (2018) 528–533

Catalysis



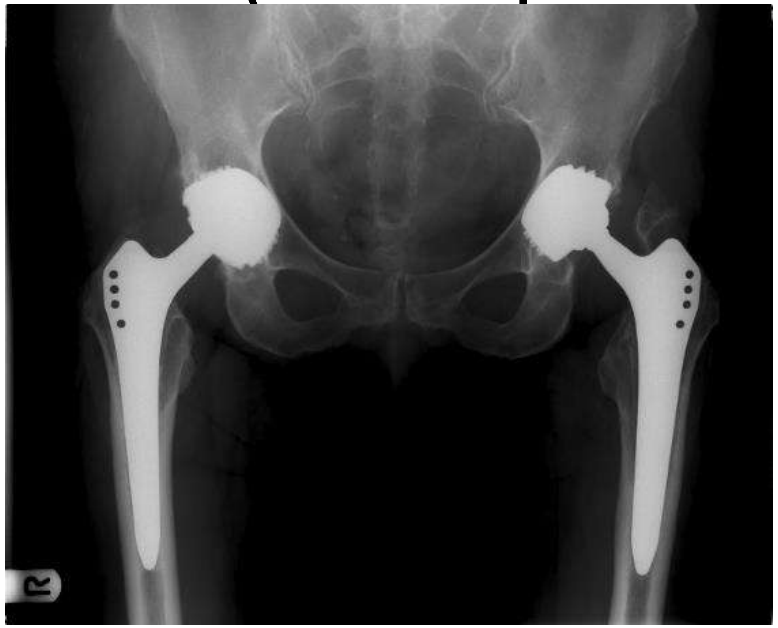
PEO catalyst for CO oxidation

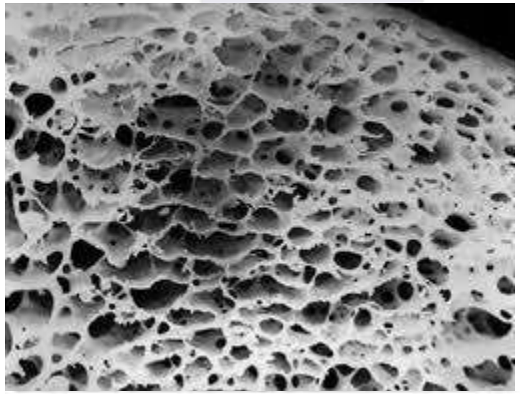


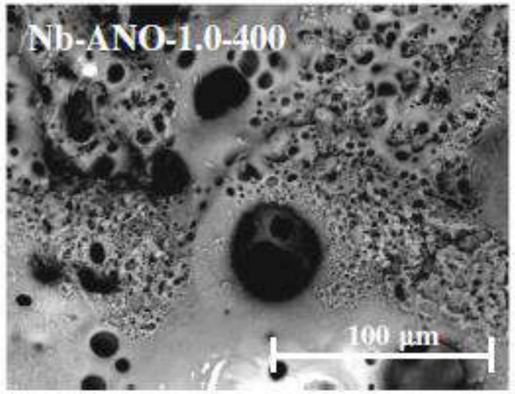
I.V. Lukiyanchuk et al. / Applied Surface Science 315 (2014) 481–489

PEO ceramic coatings

(in bone replacement)



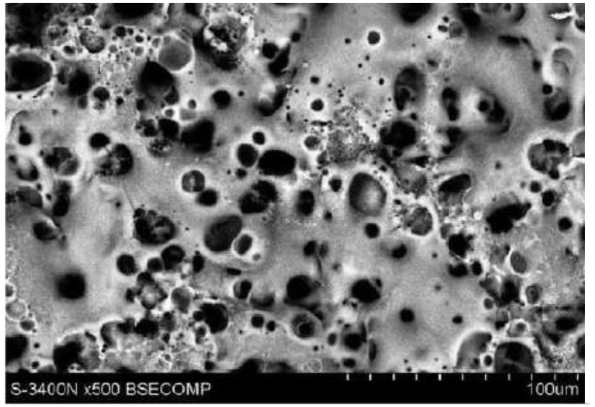


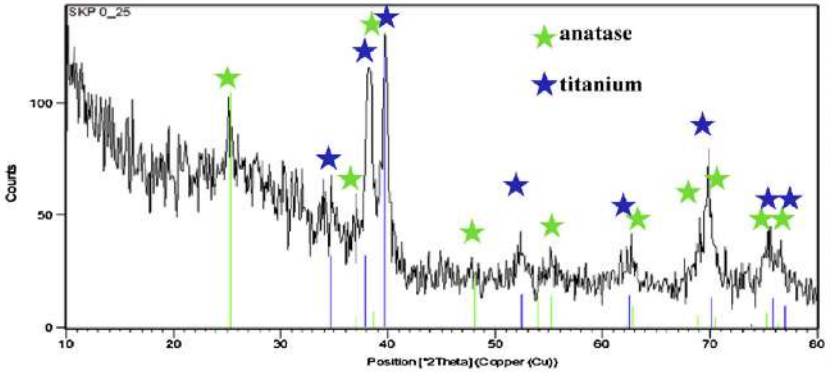


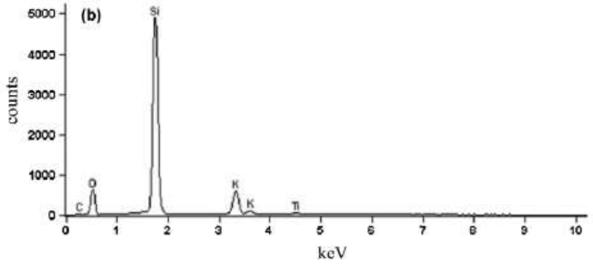
www.orthozehetgruber.at / M. Sowa et al.. J Solid State Electrochem (2014) 18:3129–3142

Biomaterials

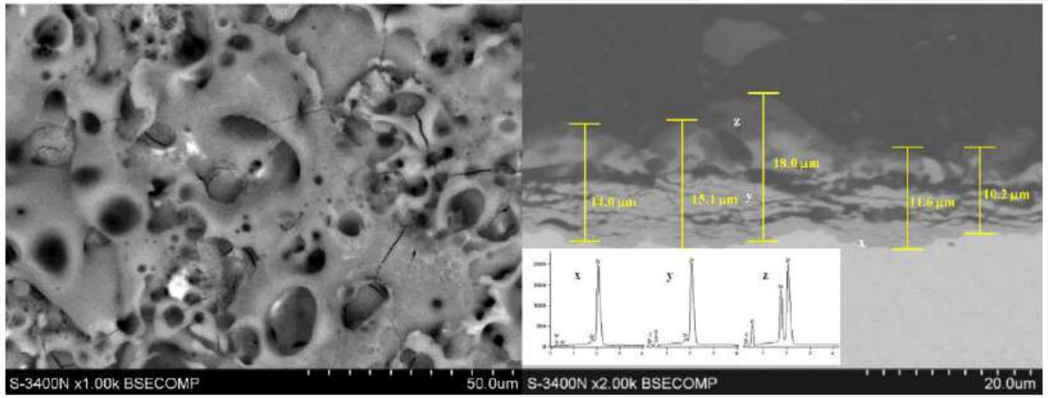
Si addition

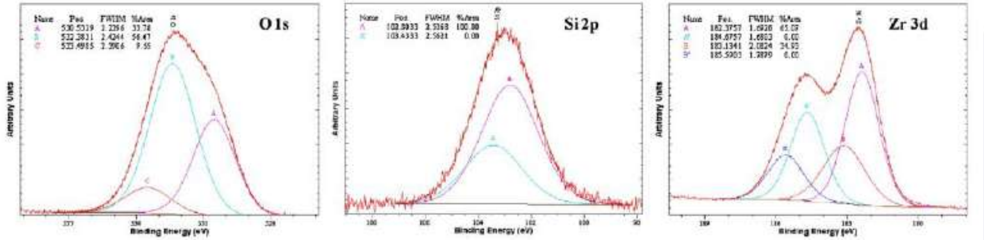






Ti-13Nb-13Zr alloy after PEO process in silicate solution; 400 V



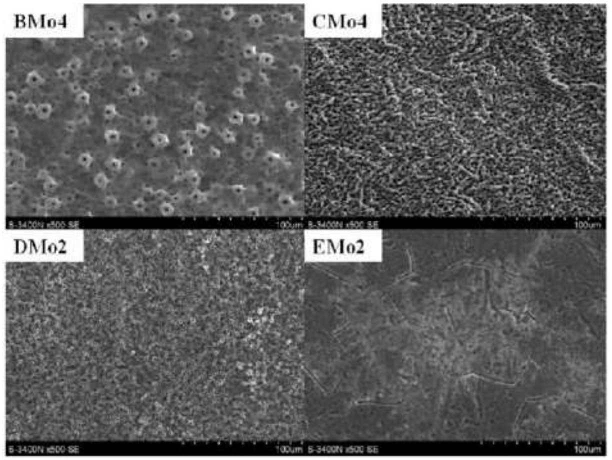


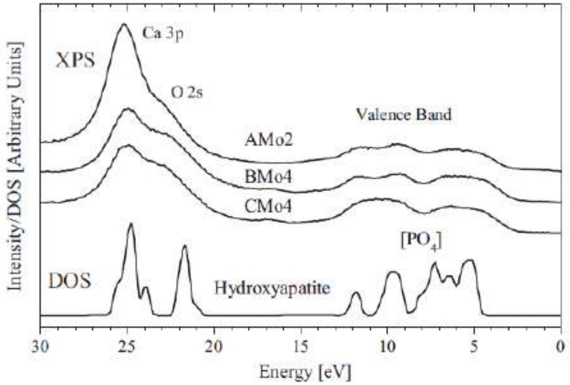
Zr after PEO process in silicate solution; 400 V

W. Simka et al. / Applied Surface Science *279 (2013) 317– 323* / W. Simka et al. / Electrochimica Acta *104 (2013) 518– 525*

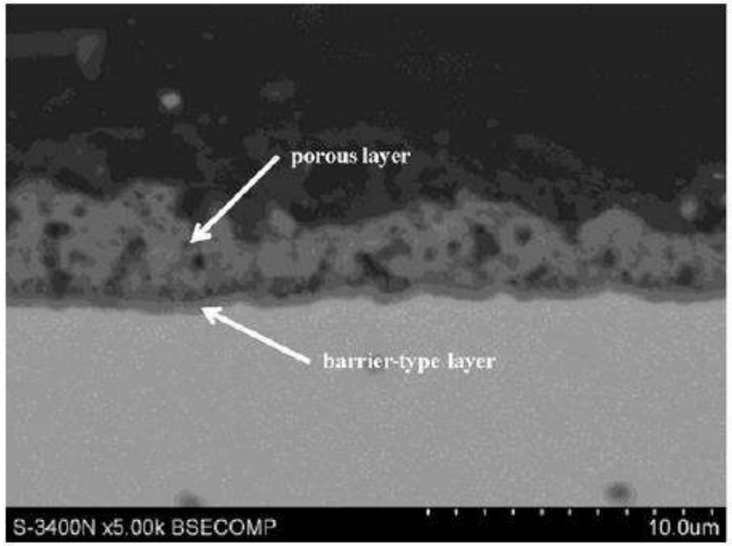
Biomaterials

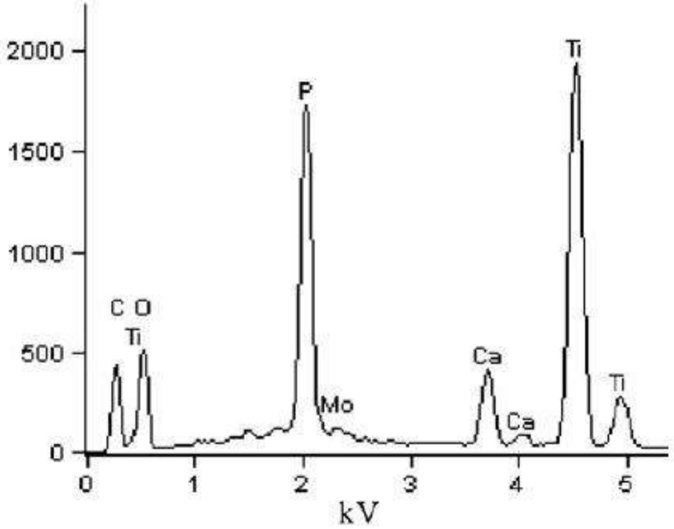
Ca, P addition





Ti-15 Mo alloy after PEO process in Ca-P solution; 200-400 V

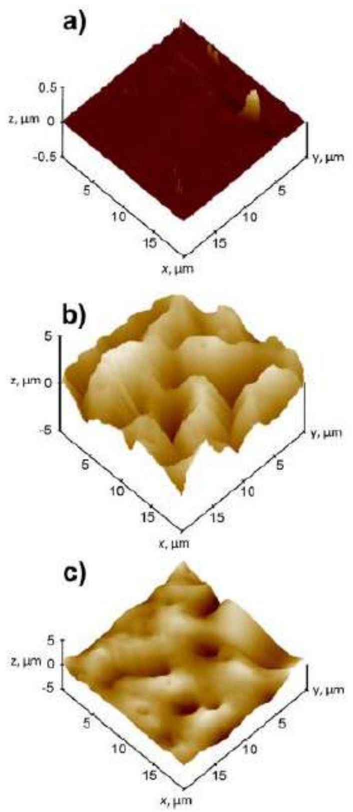


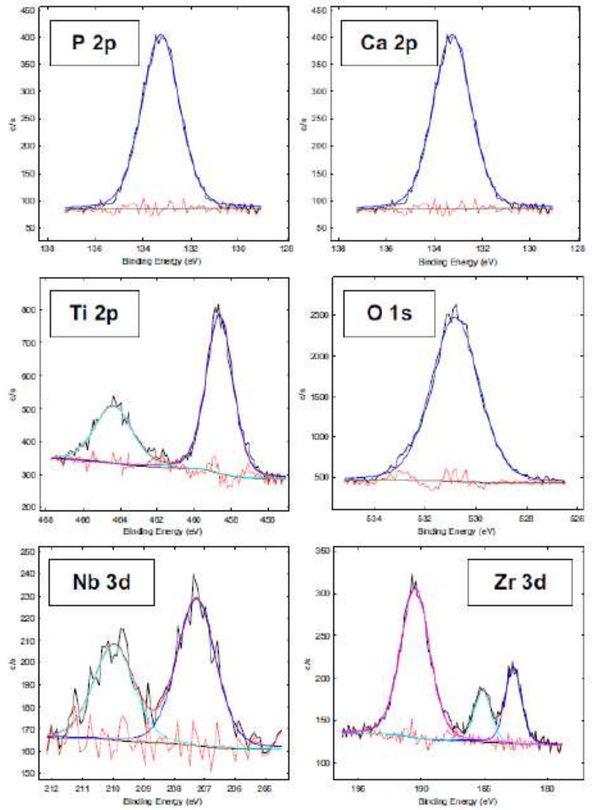


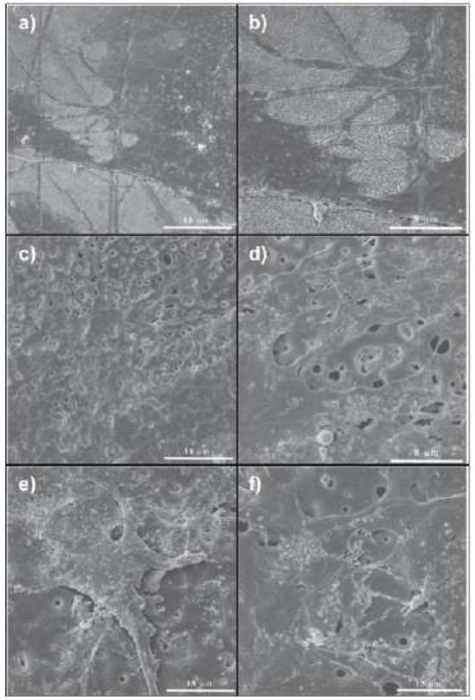
W. Simka et al. / Electrochimica Acta *96 (2013) 180– 190*

Biomaterials

Ca, P addition





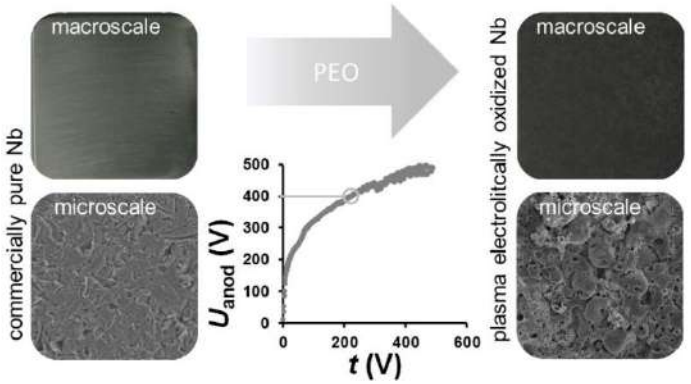


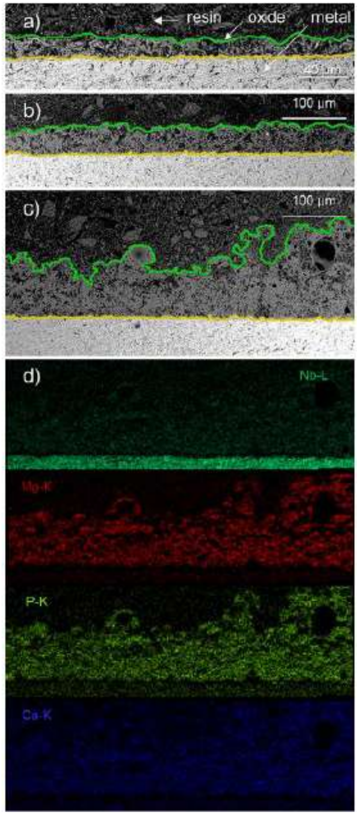
Ti-13Nb-13Zr alloy after PEO process in Ca-P solution

M. Sowa et al. / Materials Science and Engineering C 49 (2015) 159–173

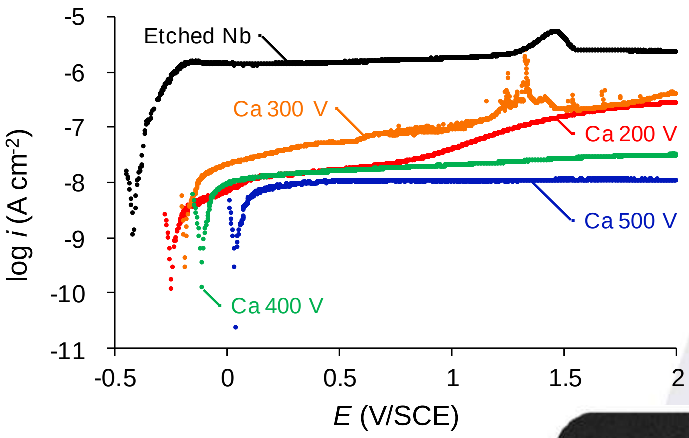
Plasma electrolytic oxidation (PEO)

Ca, Mg, P addition

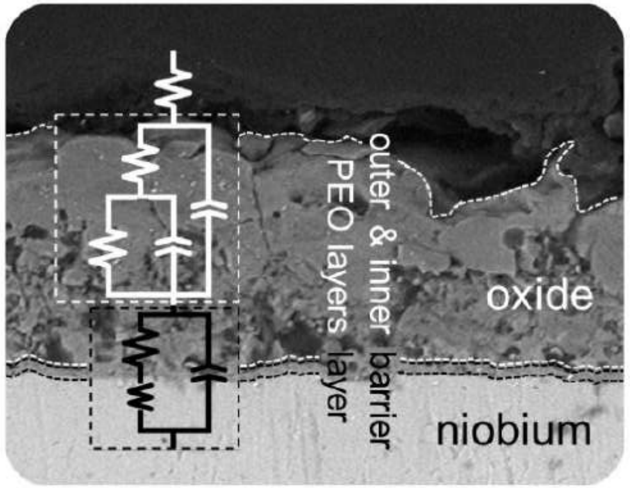




Nb after PEO process in Ca-Mg-P solutions, cross-sections and EDX mapping



Polarization curves of pure Nb and Nb after PEO process in Ca-P solution,



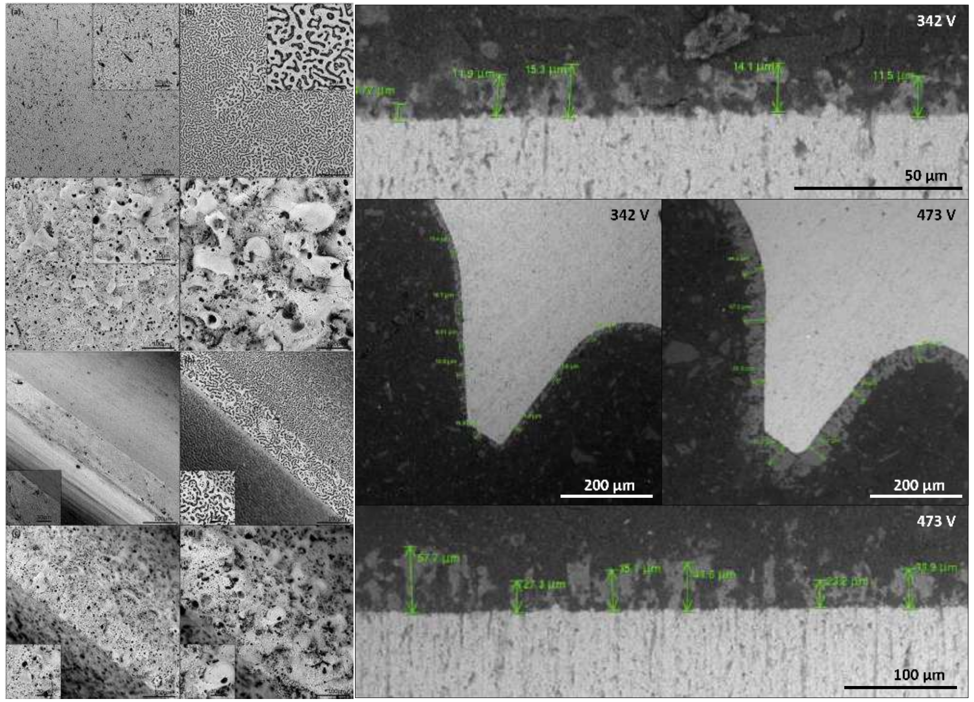
Narodowe Centrum Badań i Rozwoju

M. Sowa et al. / Electrochimica Acta 198 (2016) 91–103

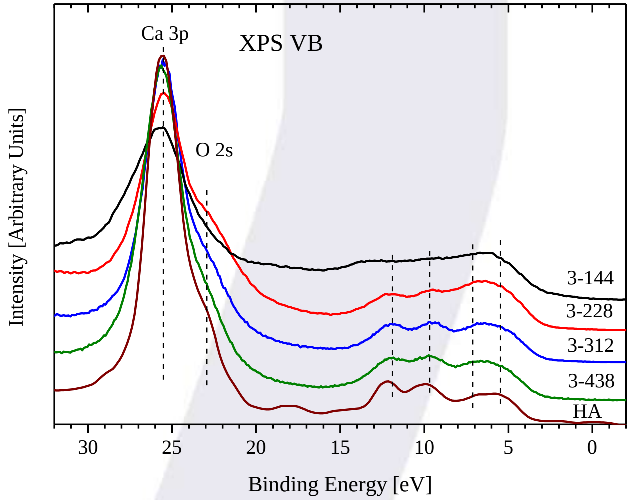
Biomaterials

PEO of GumMetal dental implants

Macro view of GumMetal samples after PEO process



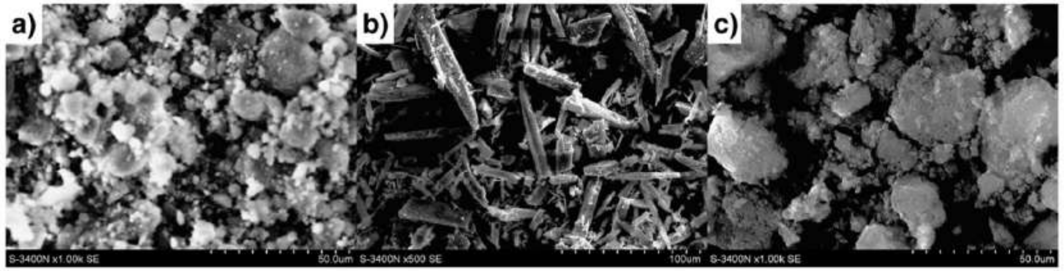
The SEM images of GumMetal samples after anodization at 128, 223, 342, and 473 V in Ca-P solution



The XPS spectra of GumMetal samples at energy range of 0–30 eV

Biomaterials

bioactive particles addition

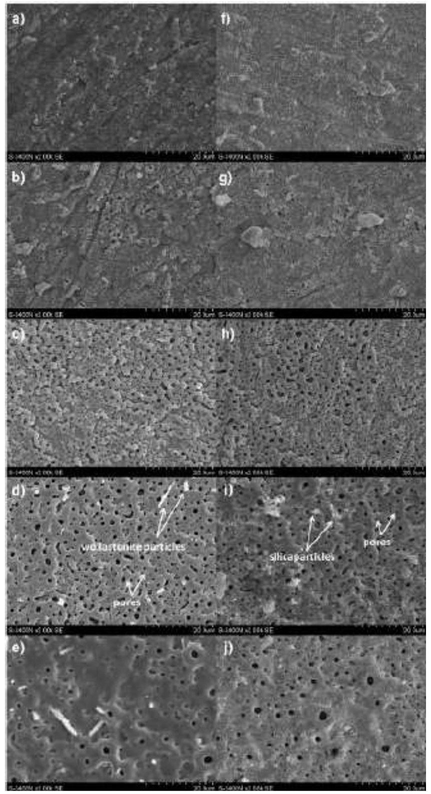


TCP wollastonite silica

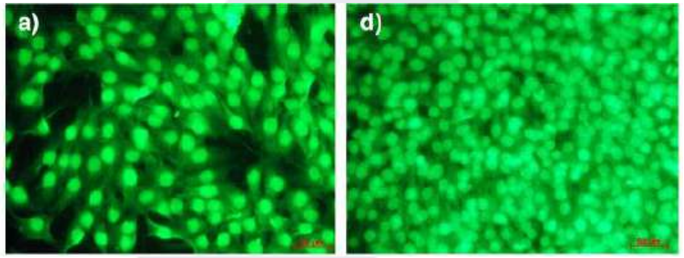
The roughness of samples and the layer thicknesses

Sample	Surface roughness [μm]				Thickness of oxide layer [μm]
	Ra	Rq	Rz	Rt	
Ti-15Mo	0.28	0.36	0.11	0.30	–
TM-200-TCP50	0.35	0.45	0.82	0.13	1.25–1.75
TM-250-TCP50	0.71	0.90	0.12	0.22	2.10–3.10
TM-300-TCP50	1.42	1.73	20.10	37.96	4.15–4.60
TM-350-TCP50	1.64	2.03	41.84	142.57	5.85–6.70
TM-300-W50	1.30	1.58	13.85	24.92	3.40–4.60
TM-300-W100	1.37	1.65	19.06	31.16	3.10–4.45
TM-300-W150	1.50	1.82	35.06	130.79	2.50–3.50
TM-300-S50	1.01	1.25	21.67	47.58	3.90–4.35
TM-300-S100	1.20	1.47	13.75	19.06	2.85–4.50
TM-300-S150	1.07	1.31	12.61	23.07	2.75–3.60

wollastonite silica



Ti-Mo alloy after PEO process in wollastonite and silica suspensions

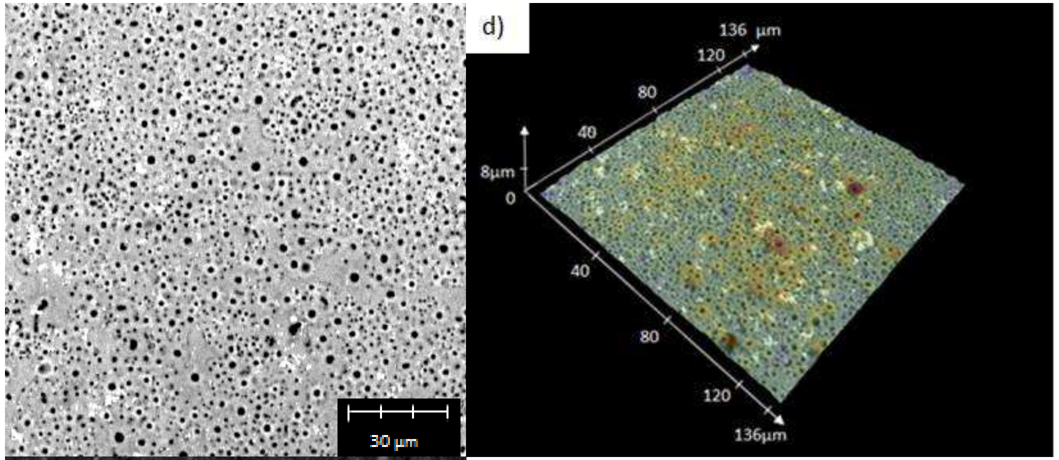


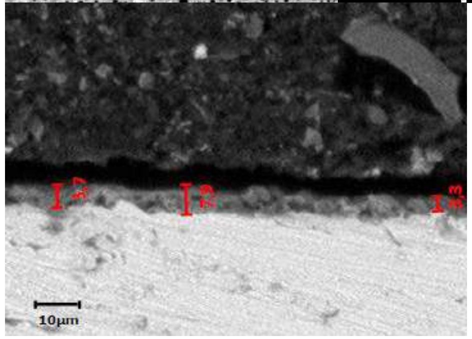
Fluorescence microscope images of MG-63 cells on 24 h (a) and 3 days (d) of culture on samples anodized in basic solution containing wollastonite

A. Kazek-Kęsik et al. / Materials Science and Engineering C 39 (2014) 259–272

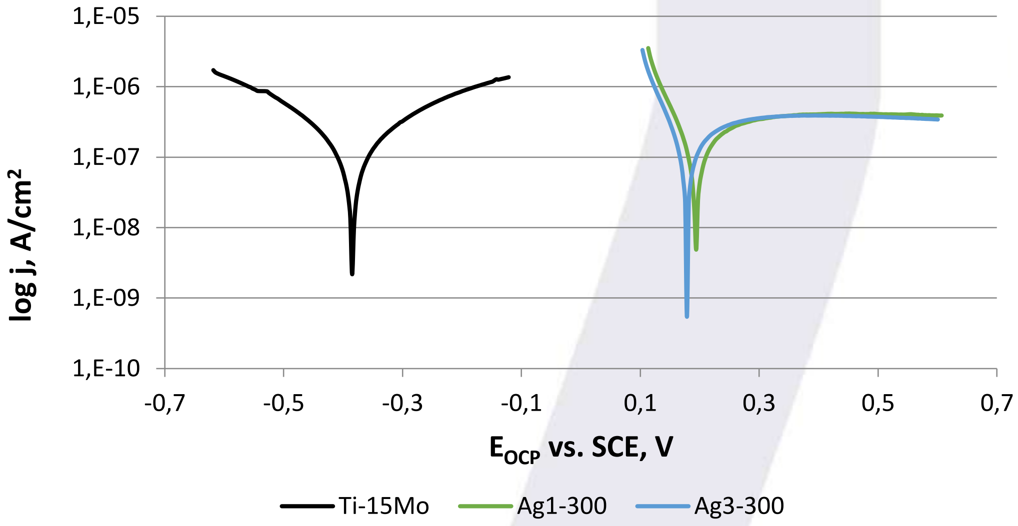
Biomaterials

Ag compounds addition





The SEM images of surface and cross section of anodized Ti-15Mo alloy as well as 3D reconstuction of its surface after PEO process

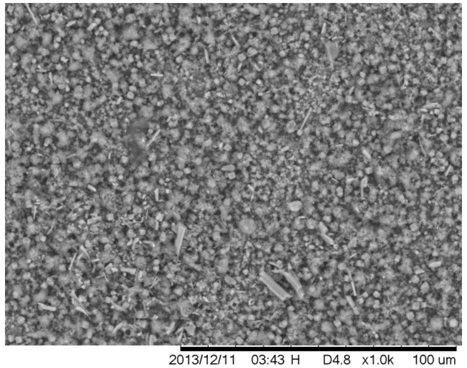


Polarization curves of Ti-15Mo alloy recorded in Ringers solution

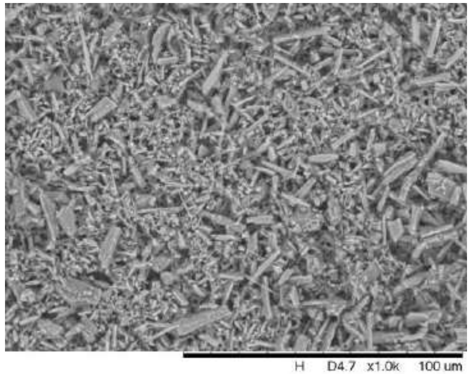
Bacteriostatic investigations are in progress

Biomaterials

deposition of ceramic particles, e.g. wollastonite

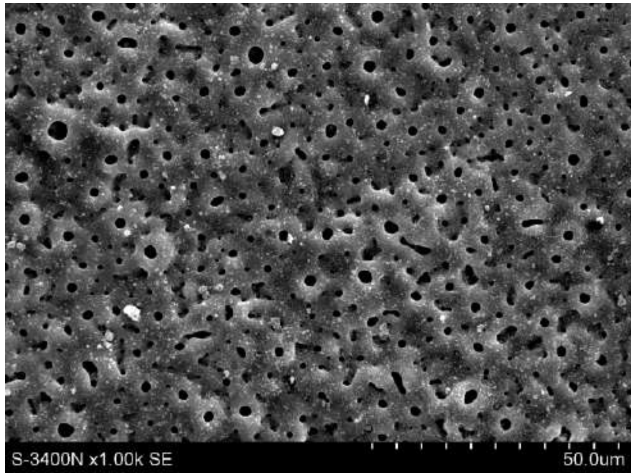


electrophoretic deposition



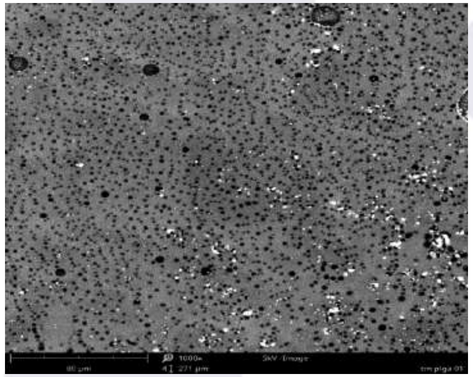
sol-gel process

porous oxide layer

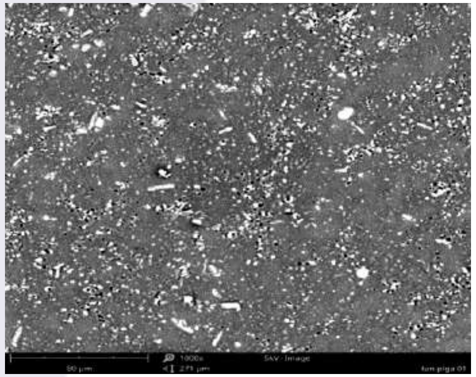


anodization of Ti alloys
in suspensions

deposition of biodegradable polymer



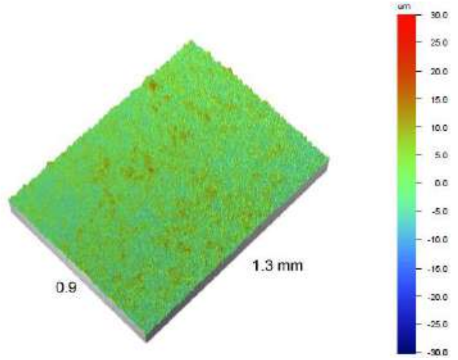
*poly(D,L-lactide-co-glycolide) 50/50 (**PLGA**)*



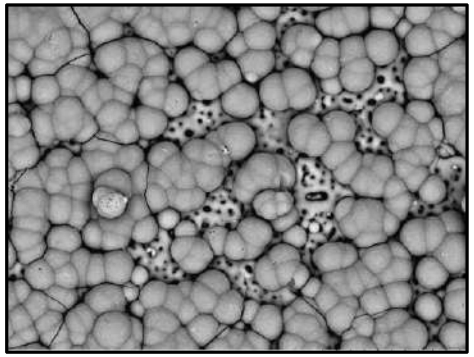
polycaprolactone (PCL)

Biomaterials

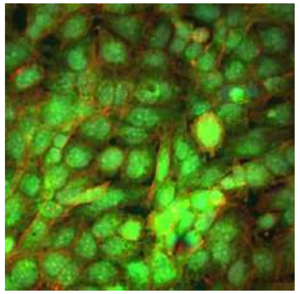
appropriate surface roughness

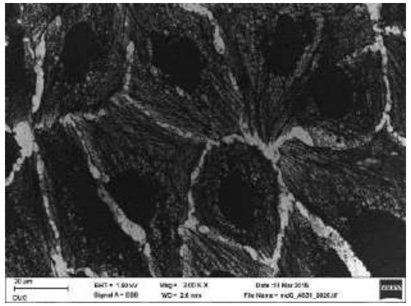


bioactive



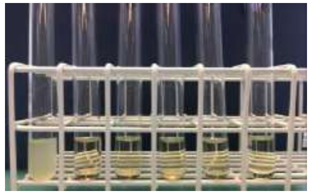
cytocompatible





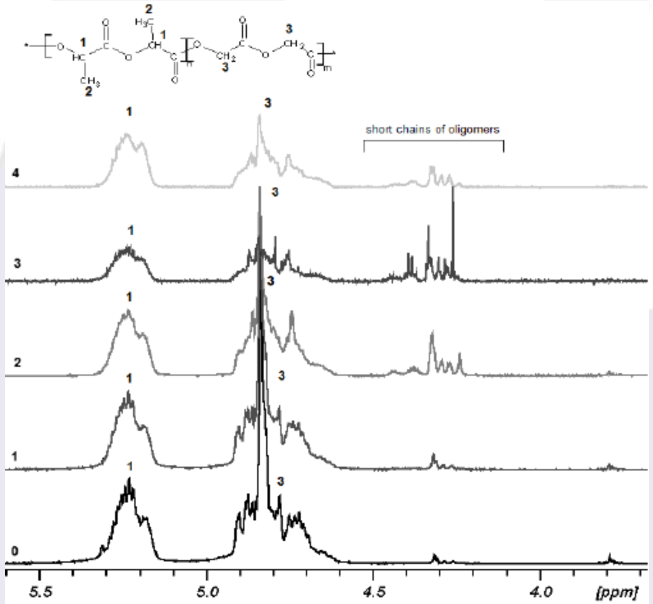
prevent ***bacteria adhesion****,*
exhibit antibaceterial properties:

Staphylococcus aureus,
Staphylococcus epidermidis
Pseudomonas aeruginosa



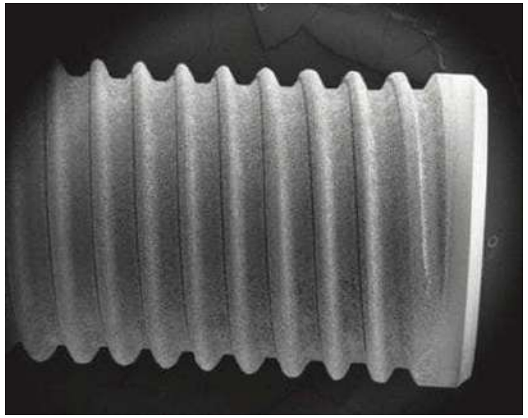
degradation of polymer layer,

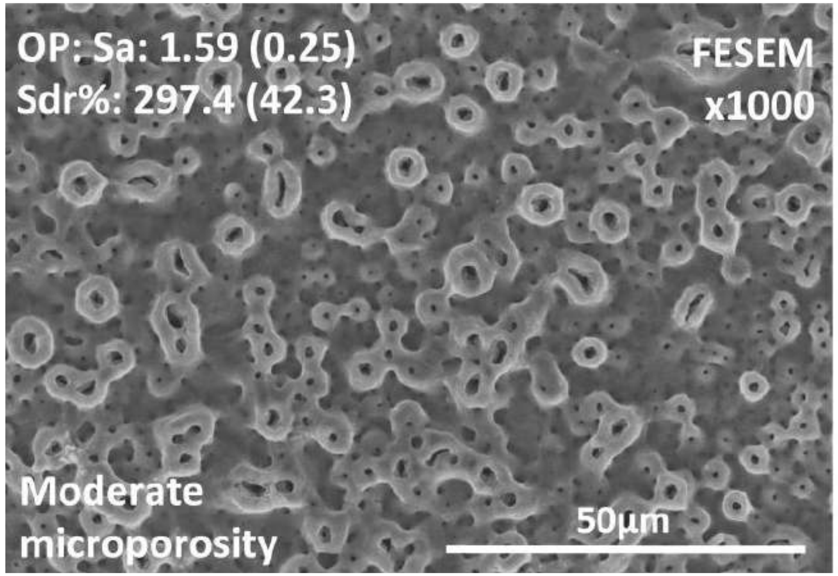
drug release

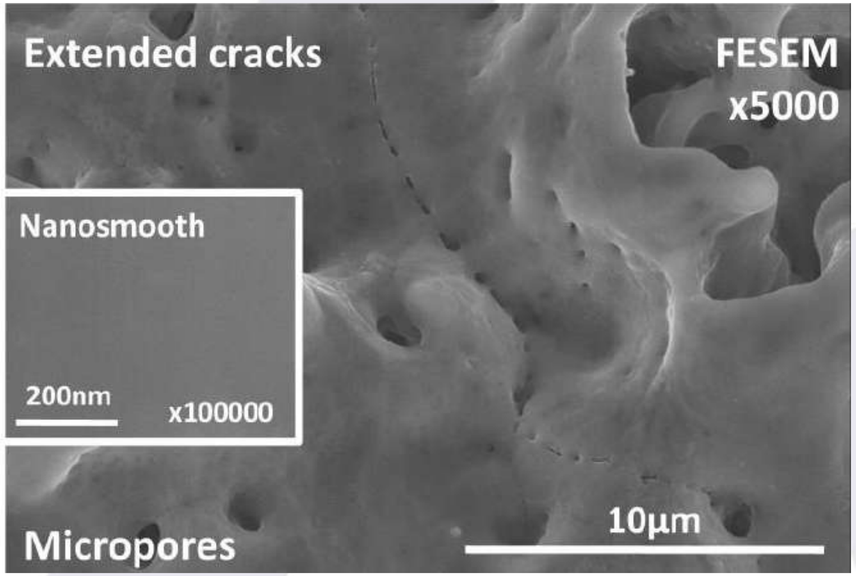


TiUnite (Replace; Nobel Biocare, Gothenburg, Sweden) (Ref:32217; Batch:432892) XPS/ESCA Surface chemical composition (%)			
Ti	14.4 %	P	7.1 %
O	55.4 %	S	0.5 %
C	21.8 %	F	0.1 %
N	0.7 %		

TiUnite™ Surface by NobelBiocare, Sweden



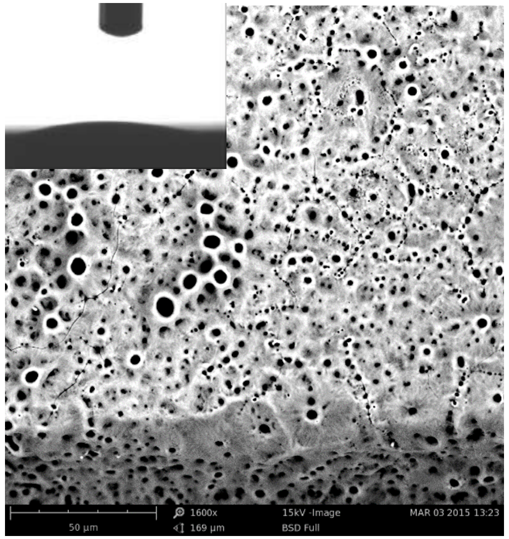


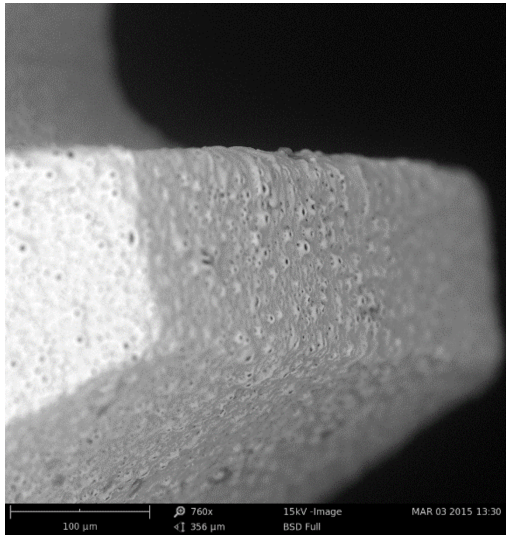


David M. Dohan Ehrenfest, POSEIDO. 2014;2(1); www.nobelbiocare@com

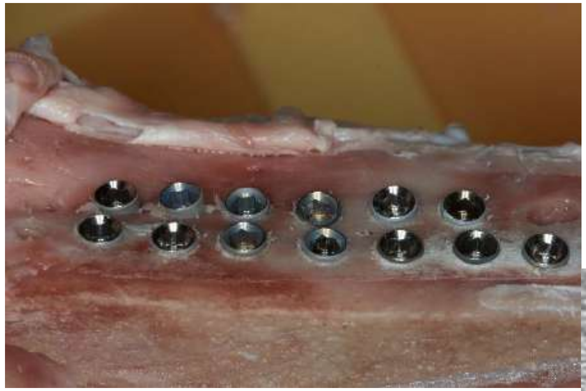
Biomaterials

PEO of dental implants with Osteoplant R&D Company, Poland

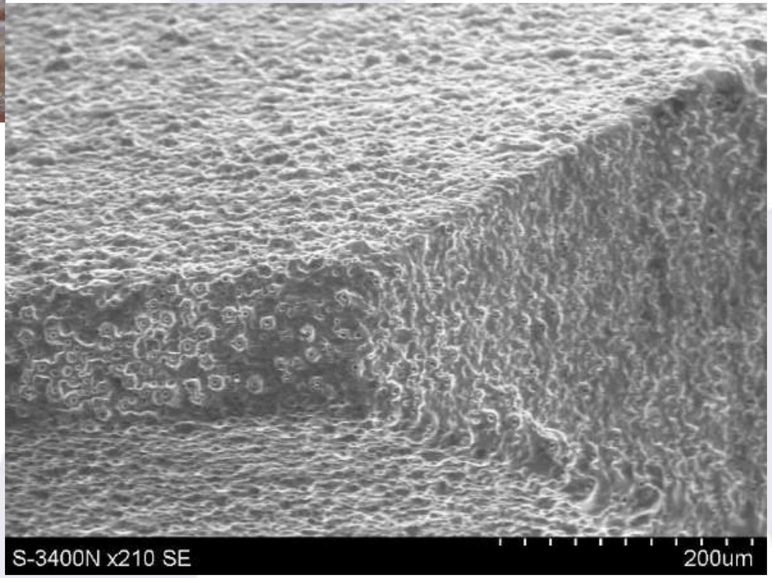




The SEM images of Osteoplant R&D implant as well as a drop view on the implant surface



Dental implants in pig mandible



The surface SEM image of dental implant after test in pig mandible

Plasma electrolytic oxidation (PEO)

Main benefits:

- **functionalization of biomaterials**
- **anticorrosive protection**
- **uniform and well adherent layers**
- **formation of (photo)catalysts**
- **anodization of complicated shapes**

Disadvantages:

I don’t have any idea☺

Thank you for attention !!!

www.electrochemistry.polsl.pl

www.osteoplant.info

Narodowe Centrum Badań i Rozwoju

Project no. POIR.01.01.02-00-0022/16, ***Development of technology and launching the production of innovative dental implants with increased osteoinductive properties***