

Ti-6Al-4V alloy: 3D printing of lightweight implants and nanopatterning by self-assembly



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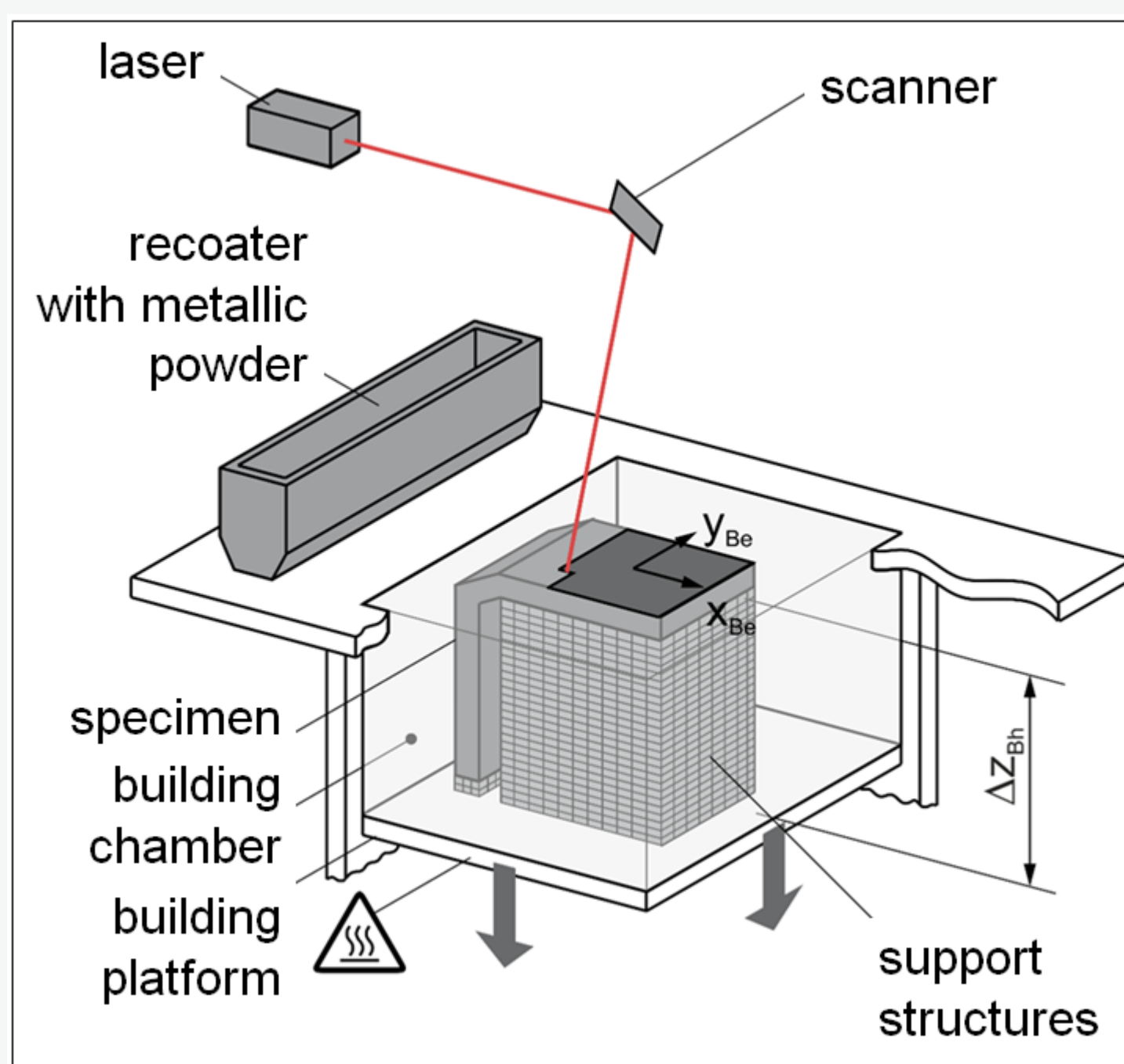


Motivation

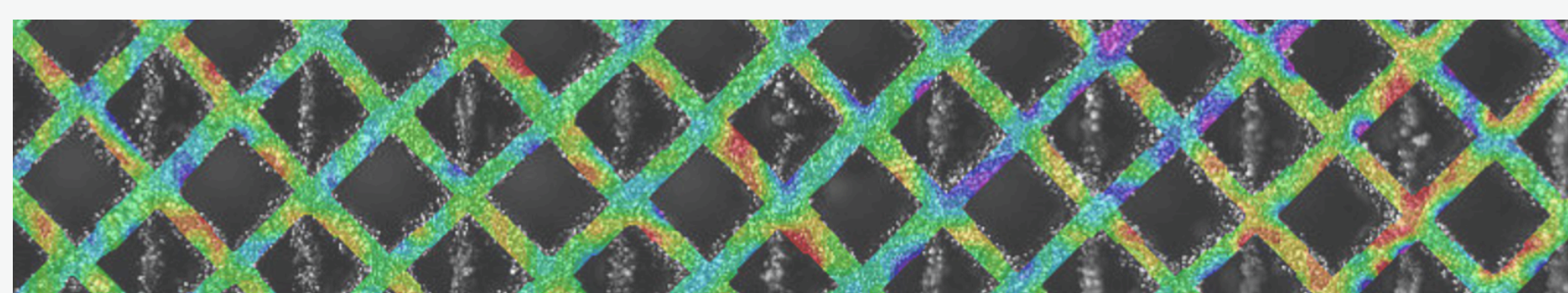
Additive manufacturing allows for custom-made design of implants and medical devices. Here, the Ti-6Al-4V alloy, which is known to show good biocompatibility, is exploited as printing material of in-vivo used elements. Besides the general materials biocompatibility, the control of cell adhesion on a surface depends strongly on the surface morphology. In this paper, we present an interdisciplinary approach combining the expertise of mechanical engineering and nanotechnology to face this problem on different size scales.

Additive manufacturing by selective laser melting

- Individual fitting
- Highly complex parts and great design freedom
- New materials and material combinations (e.g. FeAg)
- Near net-shape
- Enabling of innovative product designs and improved functionality (multi-material design, lightweight-design)

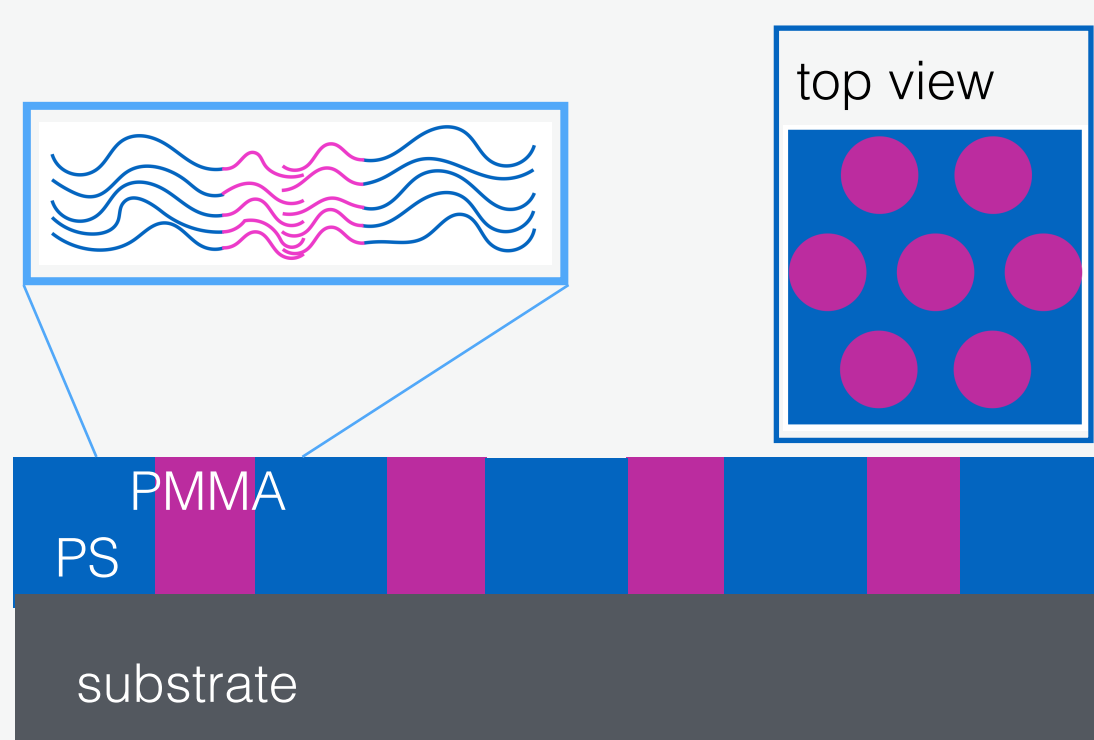


The freedom of this method to create tailored 3D device architecture allows for the local adjustment of the mechanical stability of devices.



Surface nanopatterning by block copolymer lithography

Block copolymer (BCP) lithography allows for the creation of ordered nanostructures. The microphase separation of PS-b-PMMA with a block length ratio of 70-30 for instance allows for the self-organised formation of hexagonally arranged PMMA cylinders in a PS matrix. The nanopatterns have well-defined dimensions in the sub-20 nm regime.



This technique can be applied on different materials surfaces. The nanopattern orientation with respect to the substrate is, however, determined by the interfacial energies between the polymeric nanostructured thin film and the substrate. While non-preferential wetting of the substrate with one of the BCP polymer species results in perpendicular cylinder formation (shown above), parallel orientation of the cylinders with respect to the surface is induced in case of preferential wetting with one polymer species (see right side).

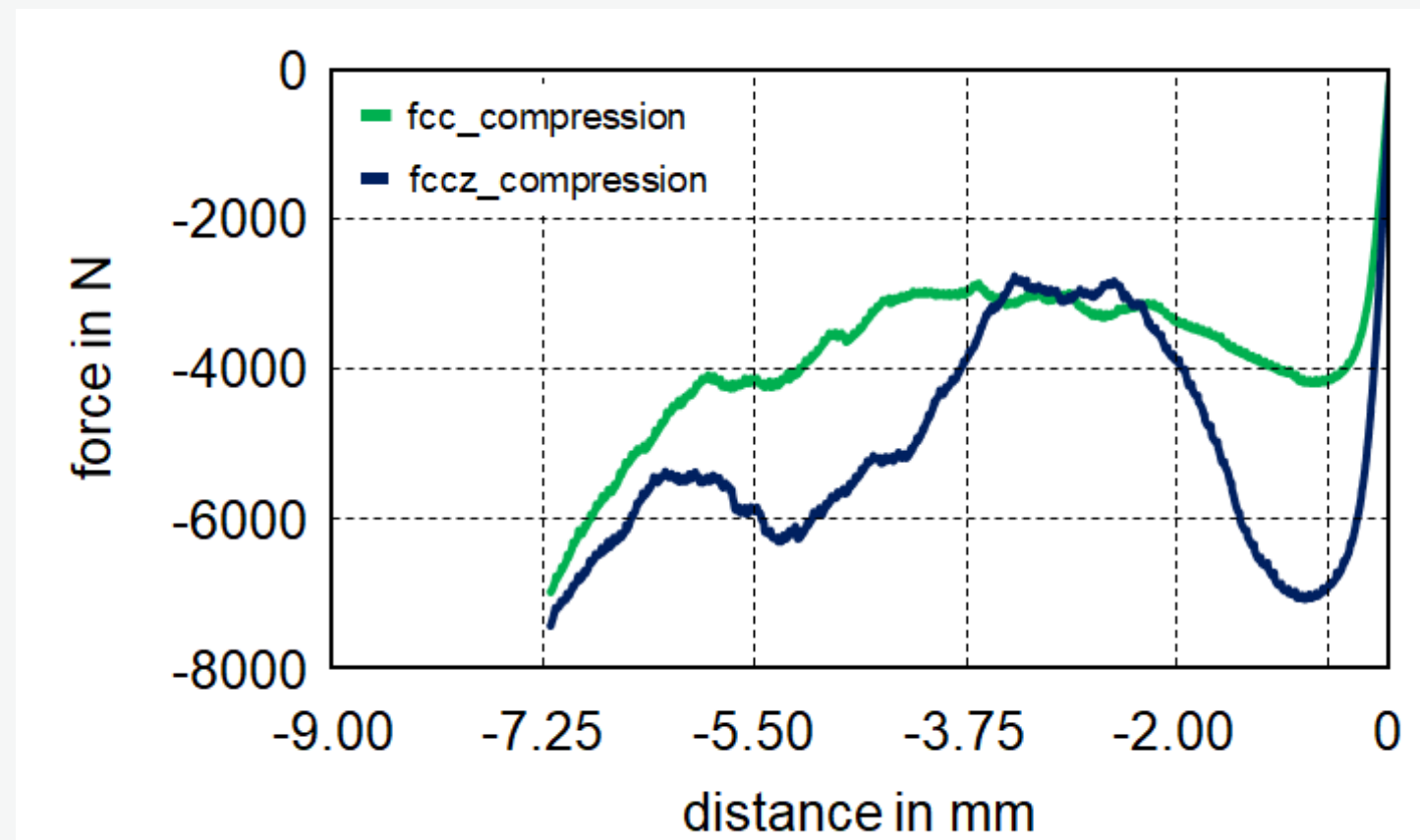
Nanopatterns with sub-20 nm feature size are known to allow for the control of interactions between biological cells and implant surfaces. Our fundamental studies aim to investigate the behavior of cells on nanostructured surfaces of 3D-printed Ti-6Al-4V under precisely controlled conditions on the well defined nanopatterns created by BCP lithography.

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Mechanical stability of 3D architectures

Experimental results and numerical simulations allow for determination of design rules for optimum device performance.

Deformation under pressure

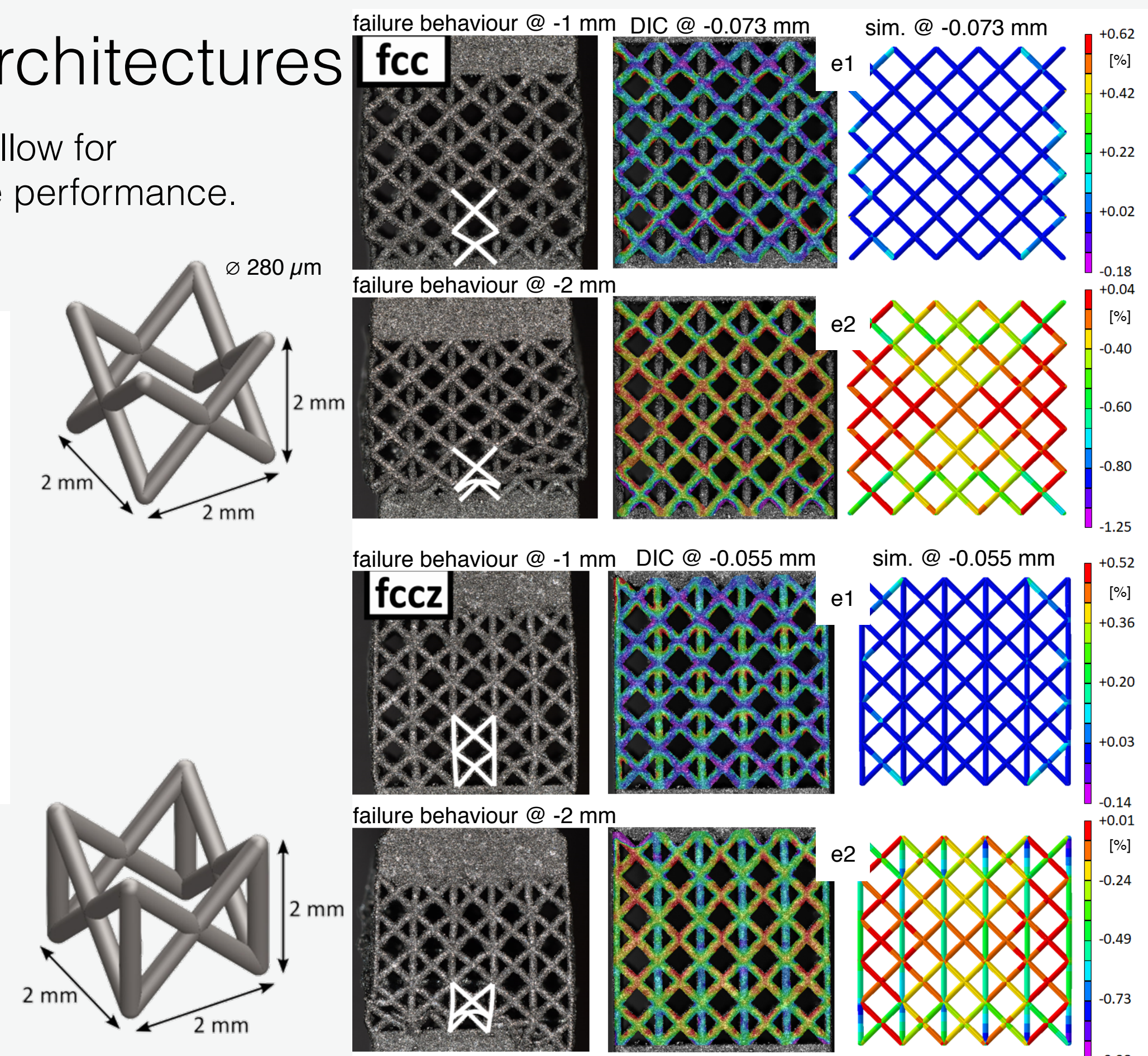


Bending-dominated applications:

→ fcc-structure

Compression/tension-dominated applications:

→ fccz-structure



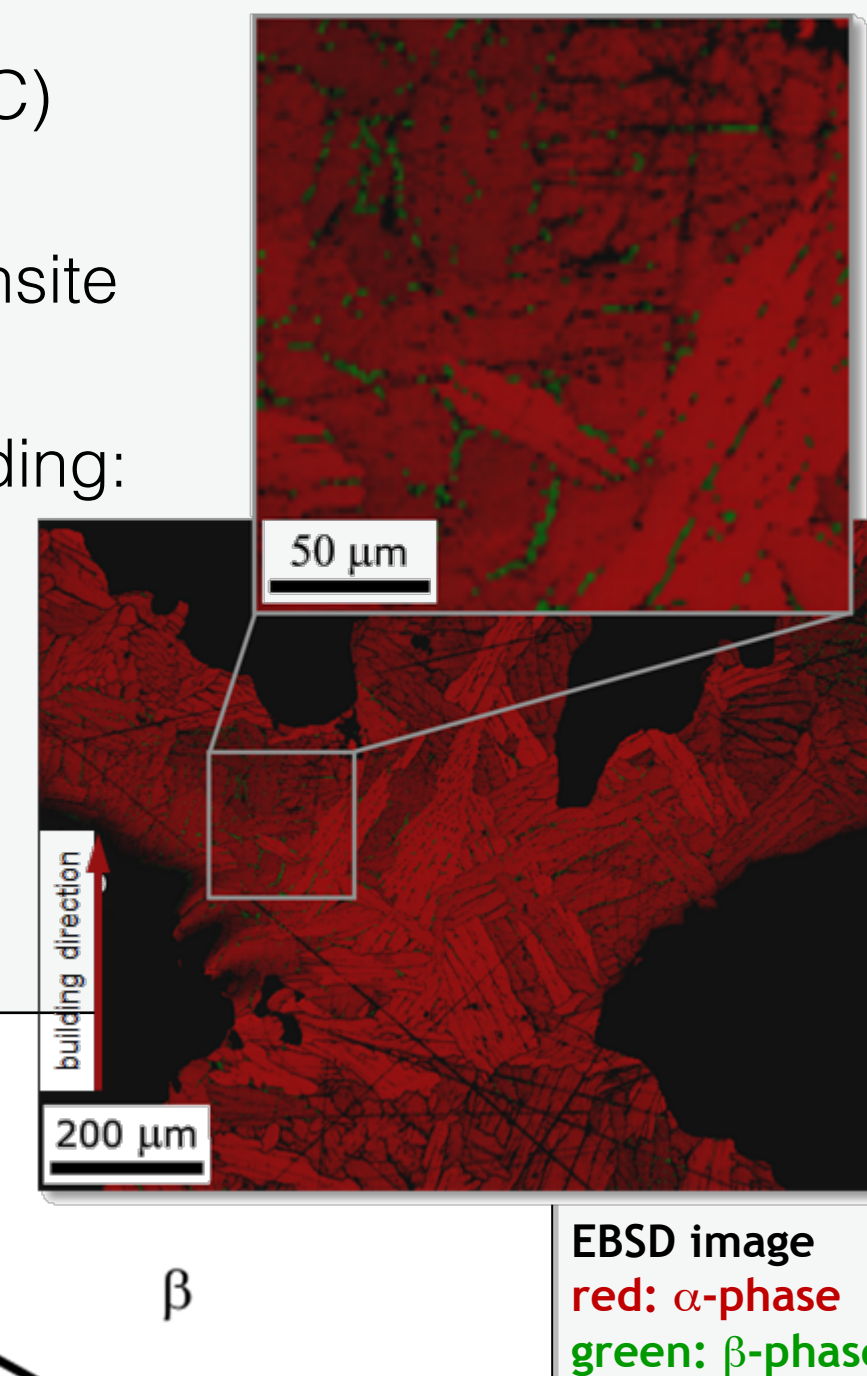
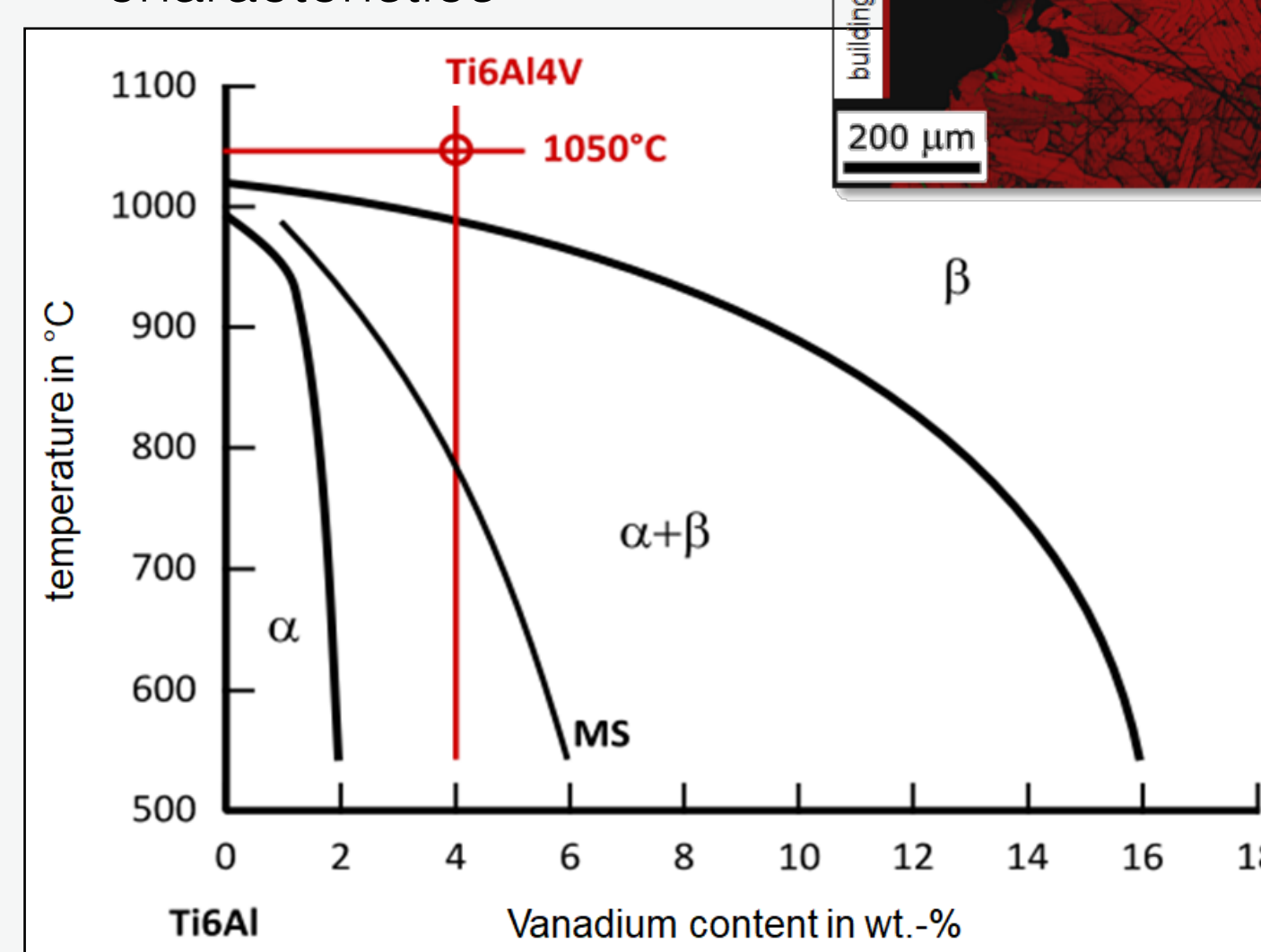
Structure & surface energy of Ti surfaces after thermal treatment

Heat treatment (2 h, 1050 °C) induces:

- transformation of α -martensite into (α + β)-phase

Resulting in a change regarding:

- mechanical properties
- physical (surface) properties
- chemical surface characteristics

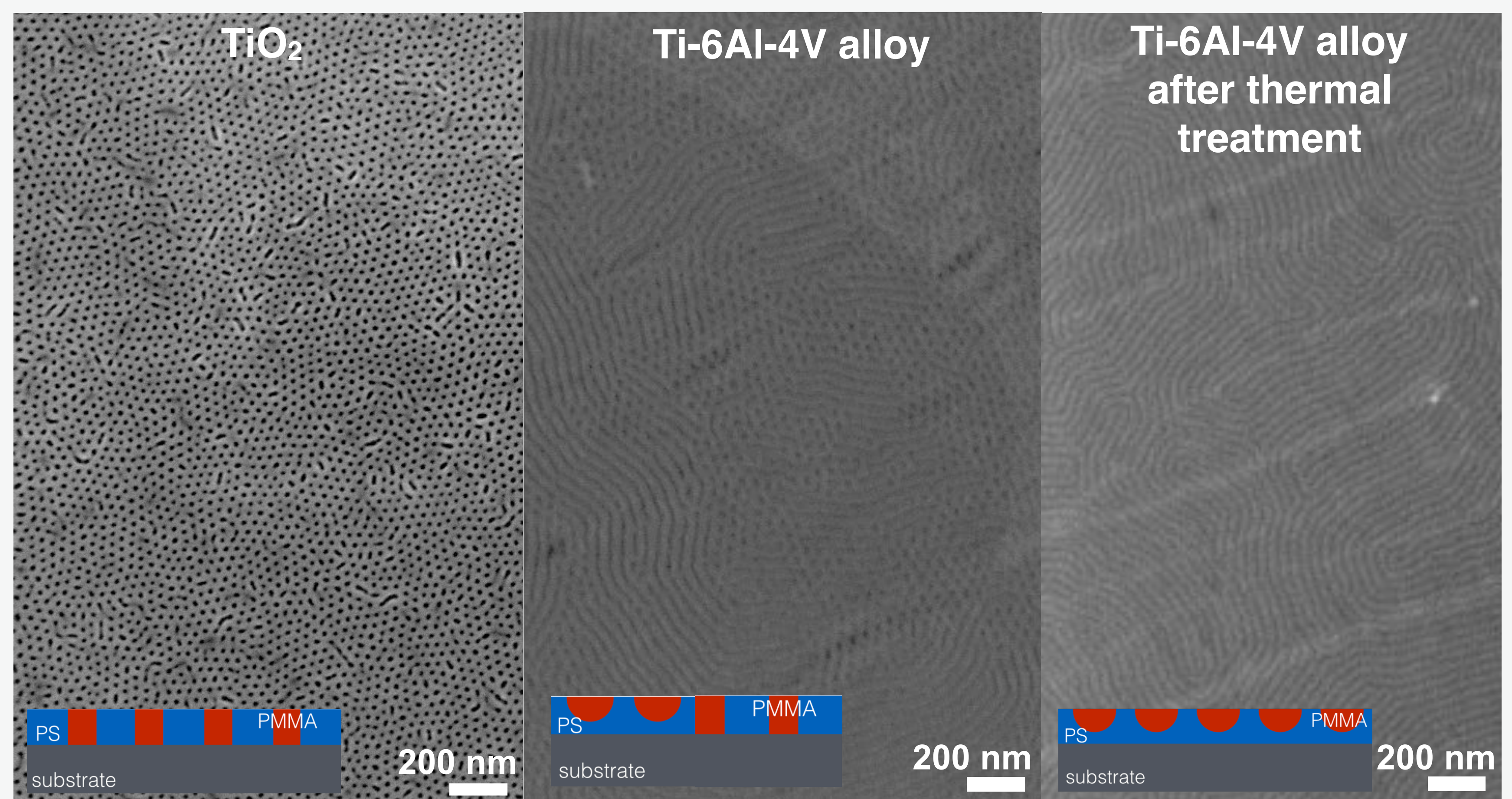


We investigate the surface characteristics of different TiO_2 surfaces, created by electron evaporation of Ti and oxidation at atmosphere, and on thermally treated 3D printed Ti-6Al-4V alloy surfaces.

	Ti (evap)	Ti-6Al-4V	Ti-6Al-4V + annealing
roughness	0.5 nm	3-4 nm	4-7 nm
SFE	39 mN/m (7% polar)	43 mN/m (26% polar)	48 mN/m (32% polar)

AFM measurements reveal that surface roughnesses on the alloy surface are small, however, larger compared to the pure Ti surface. Contact angle measurements allow for the determination of the surface free energies (SFE). The alloy surfaces show a significantly higher polar fraction of the SFE than the predominantly dispersive pure Ti. The polarity of the alloys becomes even higher during annealing.

Nanostructures on different titanium surfaces



Nanostructures in the sub 20-nm regime are created by block copolymer lithography. SEM images of nanostructured PS films on the different surfaces reveal that the pattern orientation with respect to the substrate drastically changes for the investigated surfaces. When created on pure Ti (left image) nanocylinders are perpendicularly oriented with respect to the surface (nanopores). On thermally treated Ti alloy (right image) nanopatterns are oriented parallel to the surface. This results in a fingerprint like surface pattern. A mixed state is found on the untreated alloy surface. This change of orientation results from the different surface polarities - predominantly dispersive surfaces (such as TiO_2 on pure Ti) induce perpendicular pattern orientation, while with increasing polar character (such as TiO_2 on alloys) parallel pattern orientation is preferred.