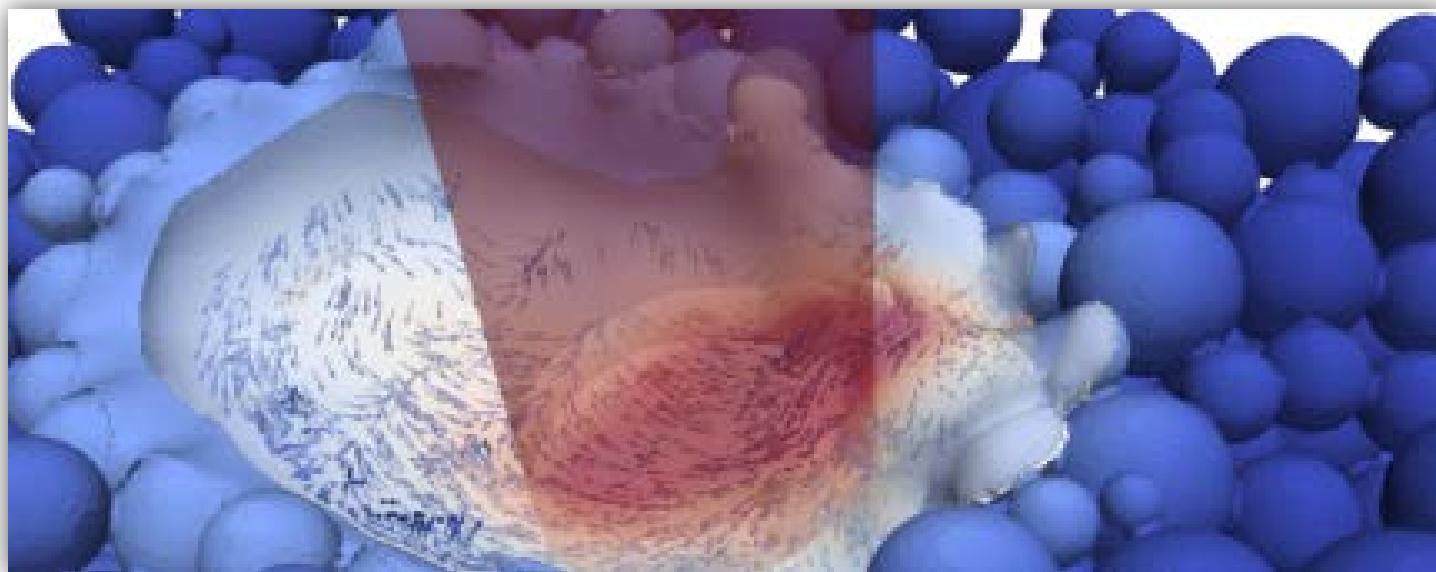


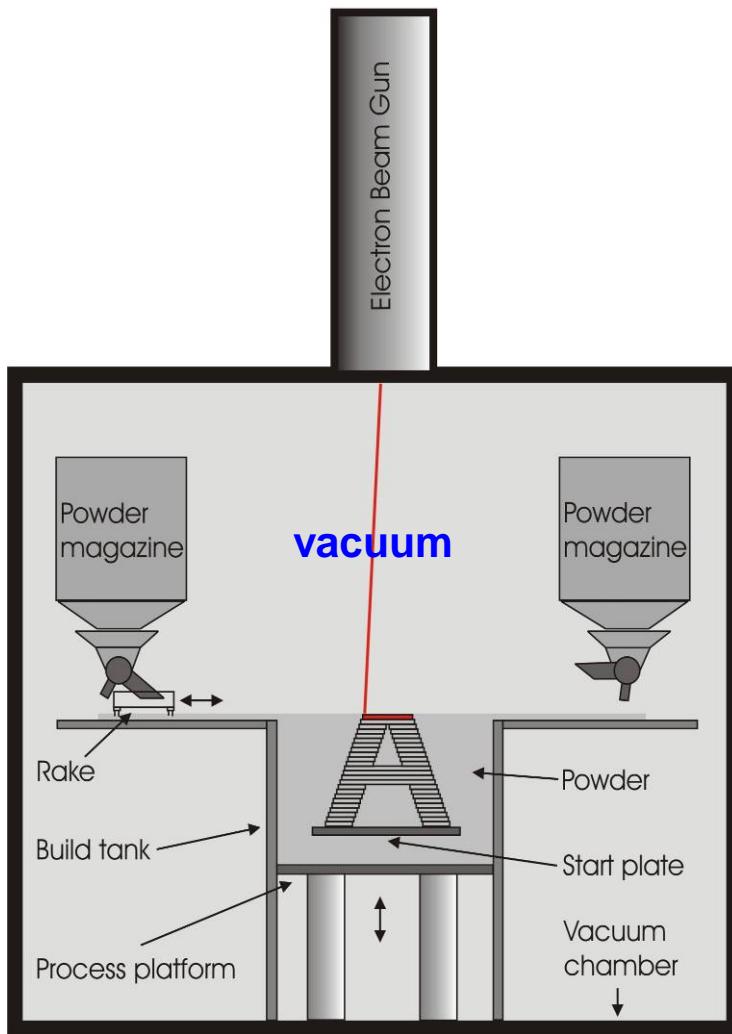
Why the development of AM alloys has to be coupled with the development of the AM process

Carolin Körner



Chair of Metals Science and Technology WTM
Department Materials Science
Friedrich-Alexander-Universität Erlangen-Nürnberg

- **Selective electron beam melting**
- **Process strategy ← → Microstructure, composition, homogeneity**
- **Prospect of material homogeneity for alloy development**



Hochgeschw. Kamera,
Thermokamera

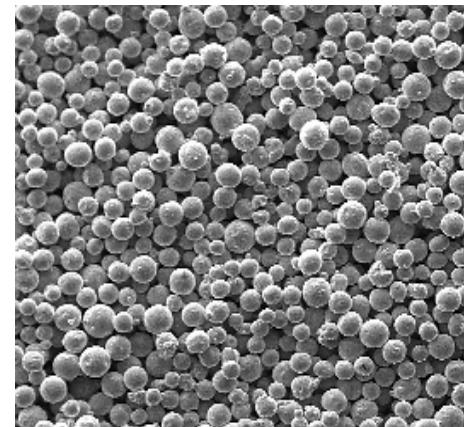
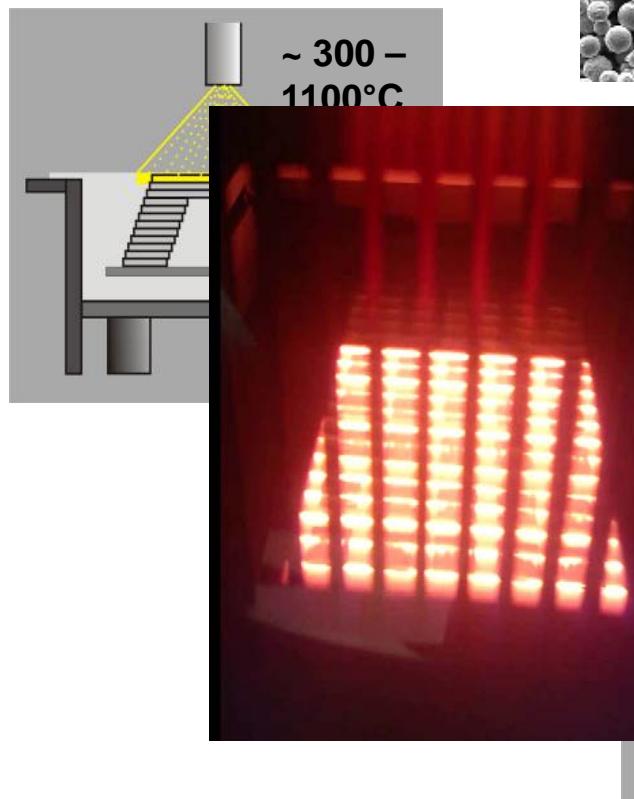
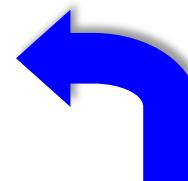
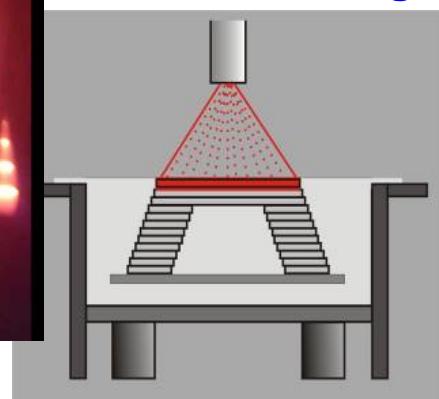
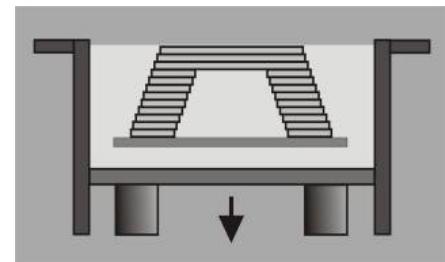


Hochtemperatur

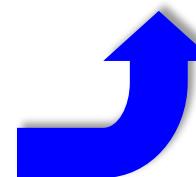


100 µm Strahl,
auch bei 3 kW

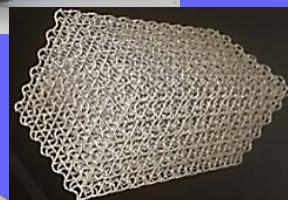


1. New powder layer**2. Heating $T > 1000 \text{ } ^\circ\text{C}$** **3. Selective melting****4. Lowering of the platform**

Layer thickness: 50 -100 μm



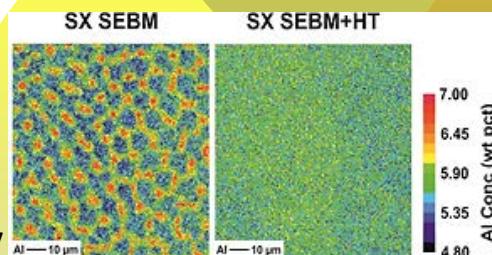
Components



Etc. CMSX-4

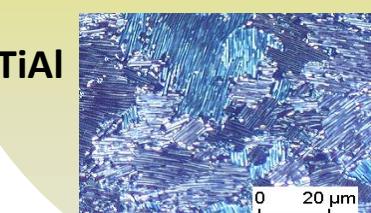
SEBM

FeAl

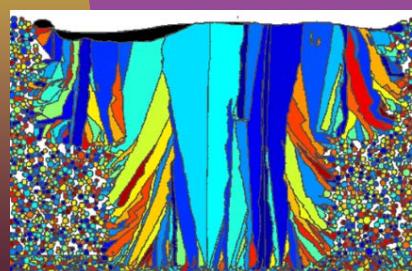
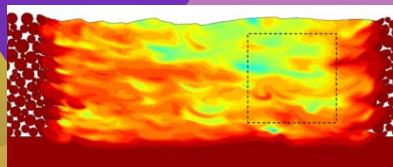


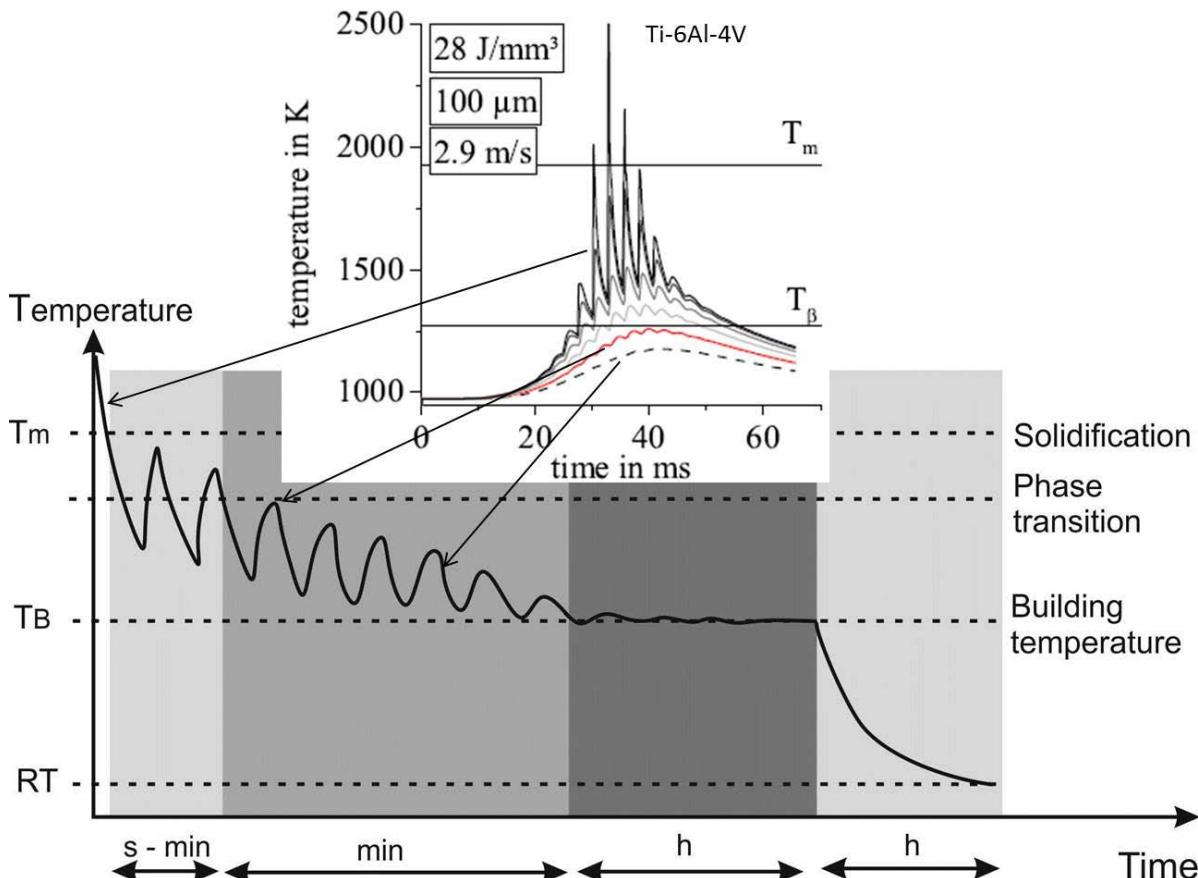
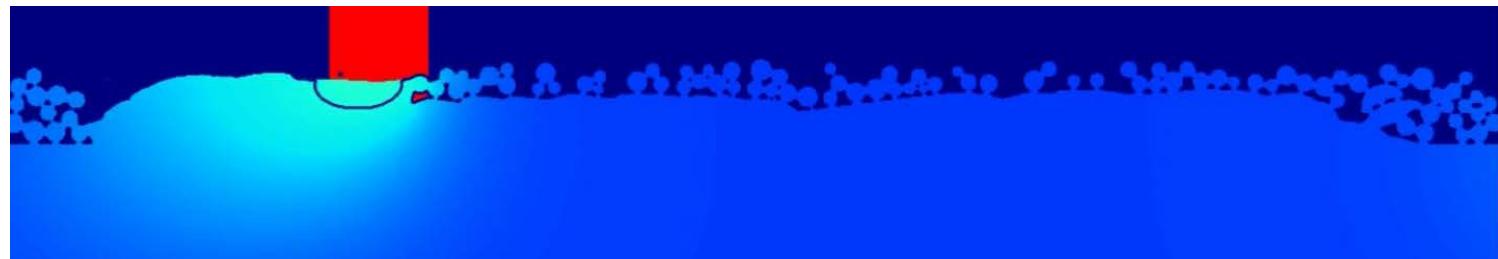
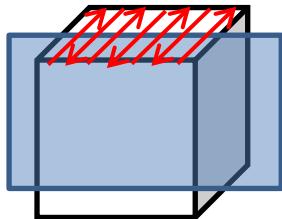
Cu

Ti-6Al-4V



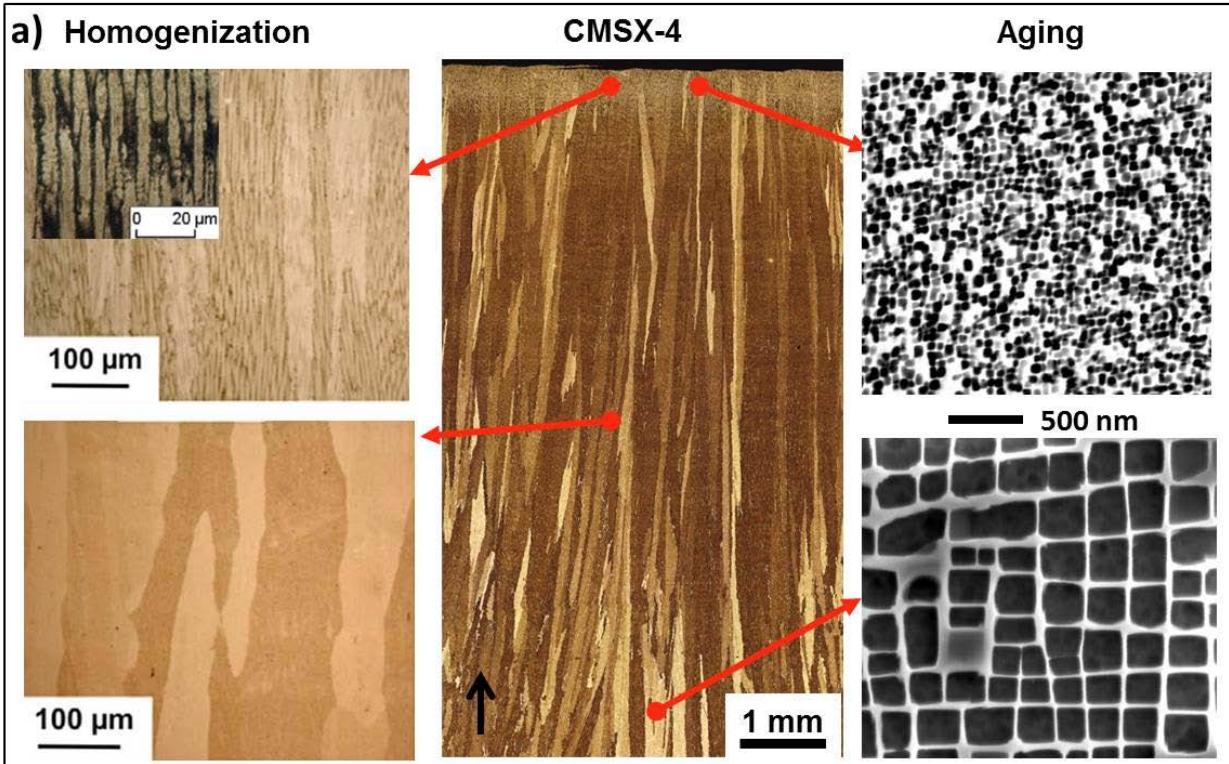
Materials

Process
simulation

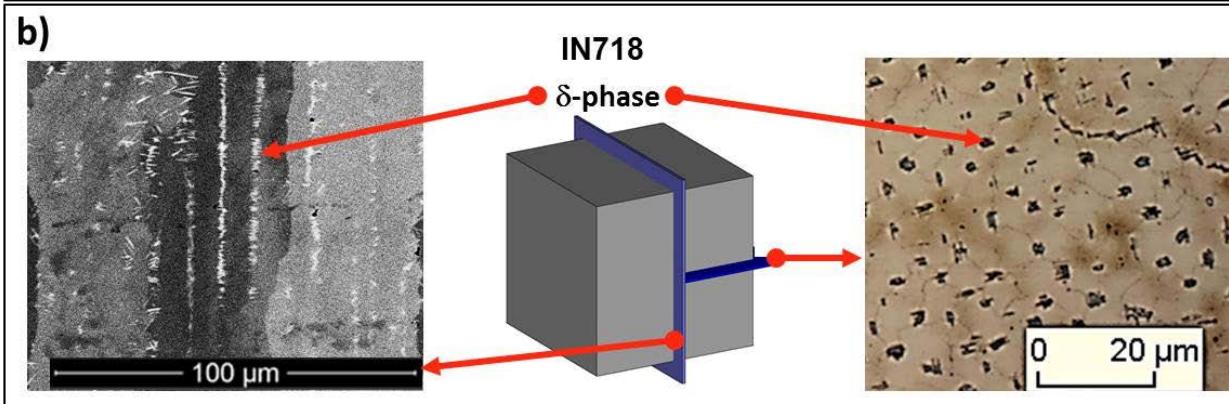


- High peak temperatures $\gg T_m$
- Very high cooling rates
- In situ heat treatment

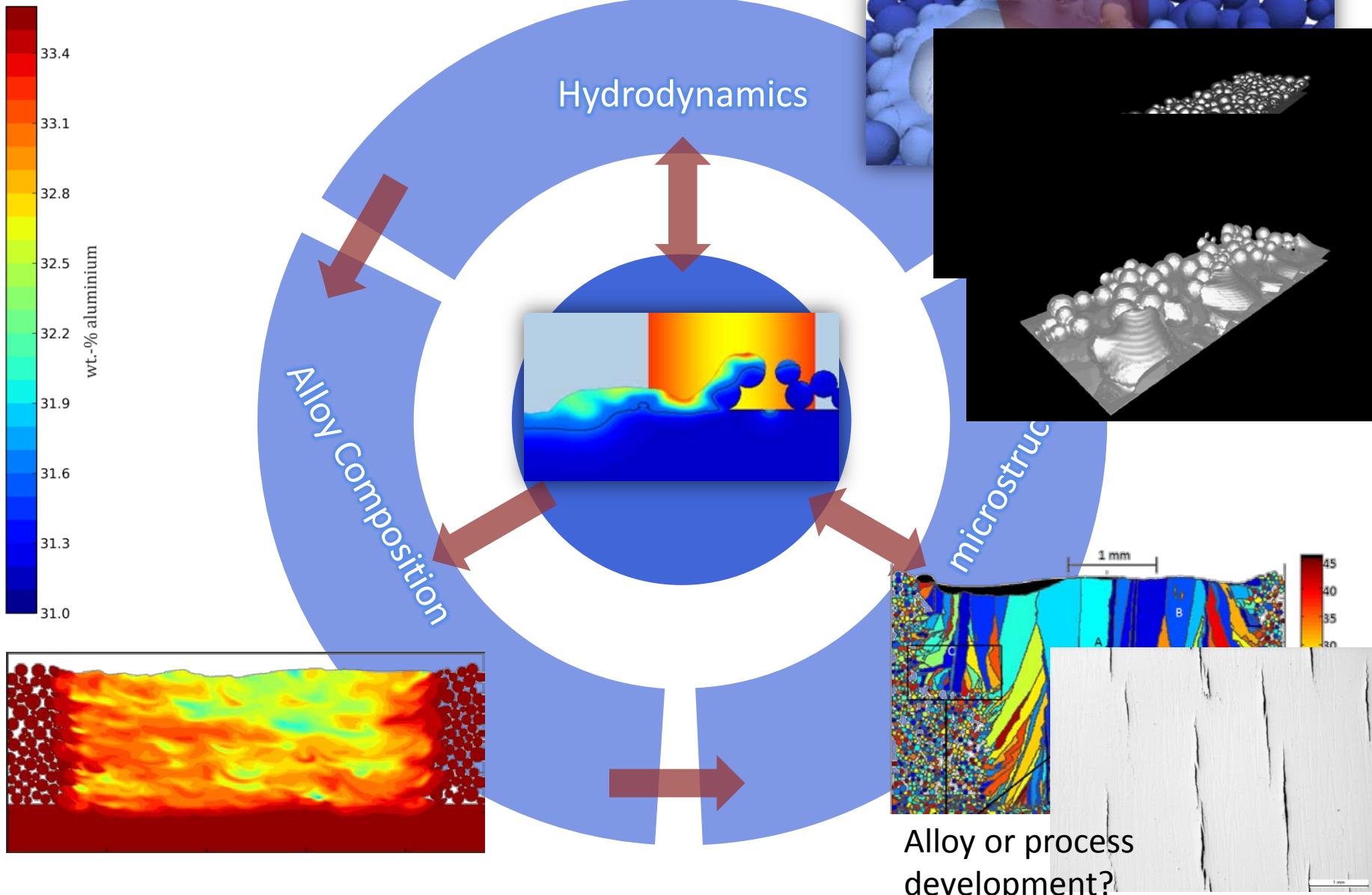
- Evaporation, also selective
- High supersaturation
- Different microstructure within the as-built state



- In situ heat treatment:
 - homogenization
 - aging
 - precipitation columns
- „Directional“ solidification:
 - epitaxial growth
 - texture
- Rapid Solidification
 - fine microstructure

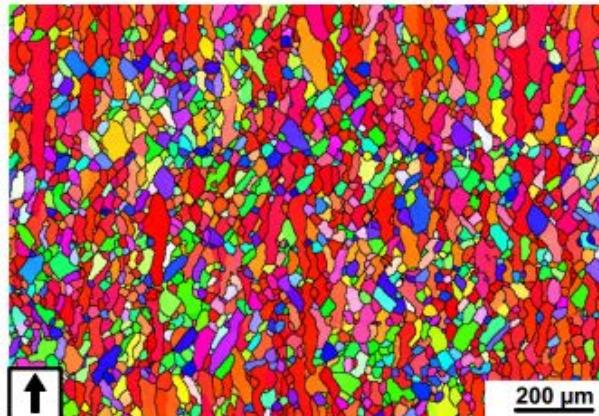
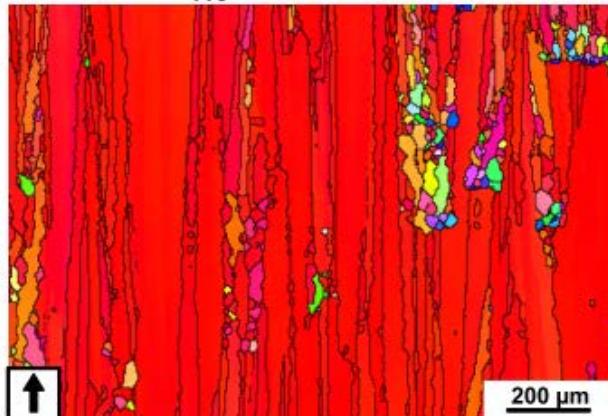


Numerical simulation for a better understanding

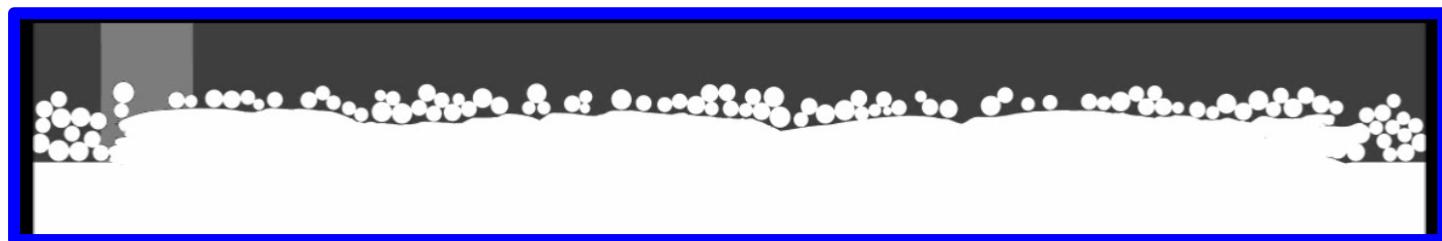
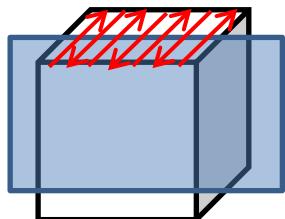


$P = 594 \text{ W}, v = 2.2 \text{ m/s}, l = 150 \mu\text{m}$ $P = 627 \text{ W}, v = 8.8 \text{ m/s}, l = 37.5 \mu\text{m}$

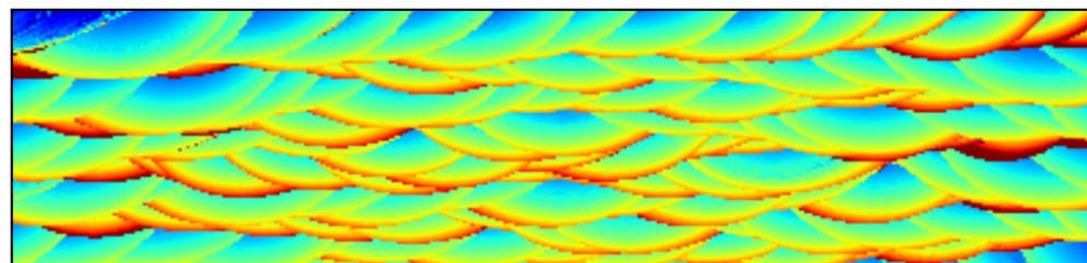
In718



Same energy input but different hatching strategies



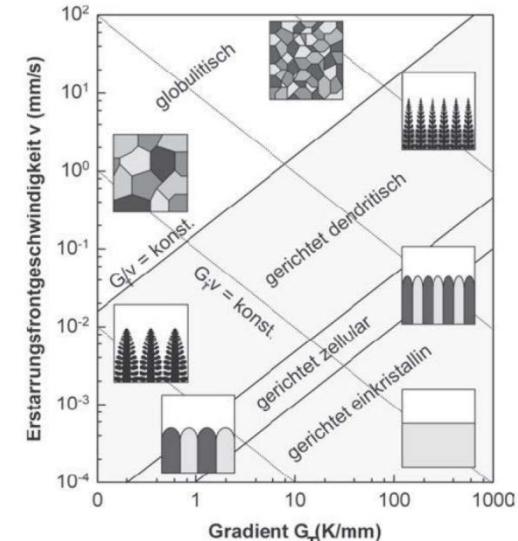
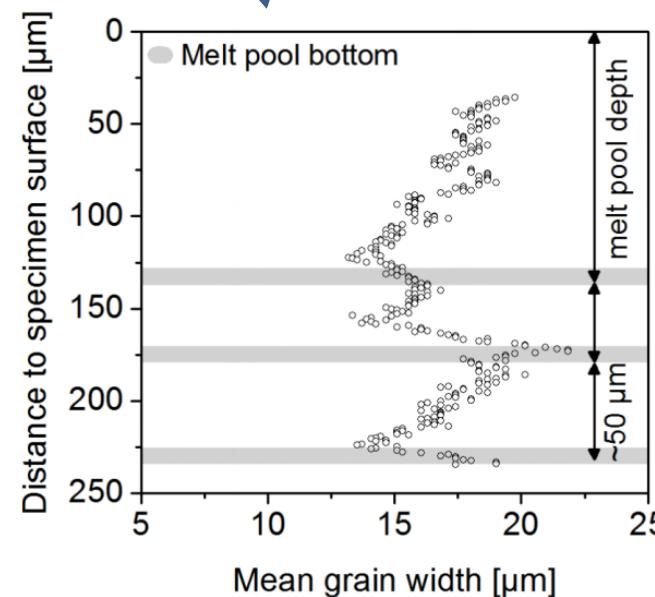
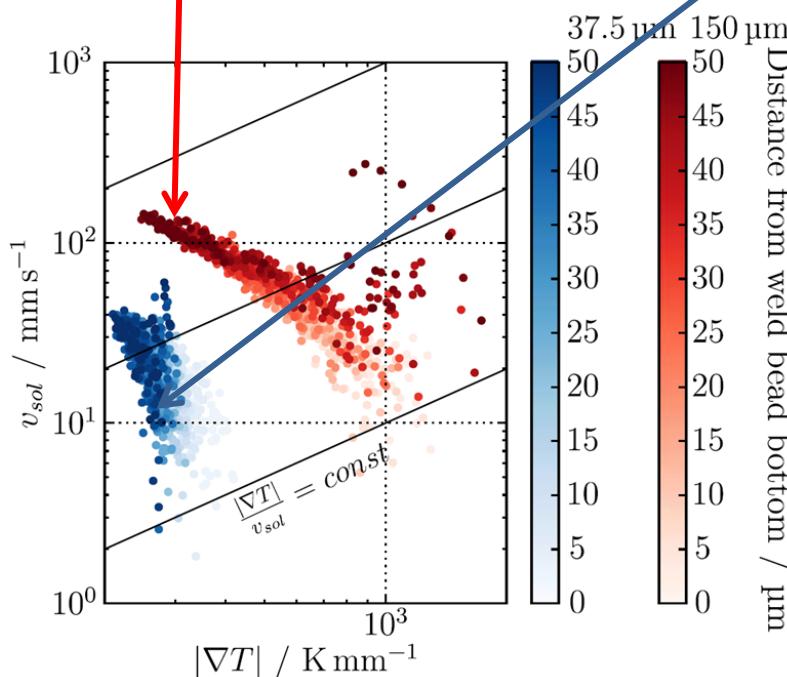
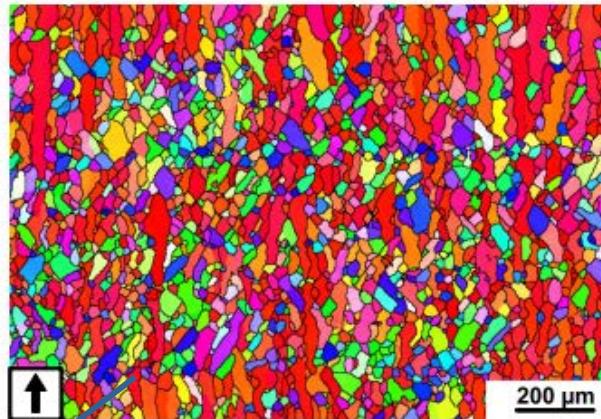
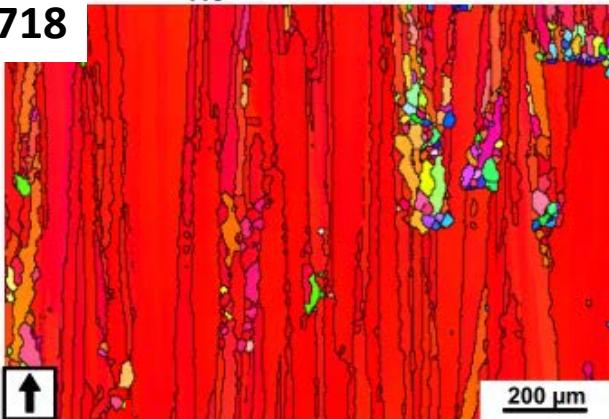
$$|\nabla T|$$



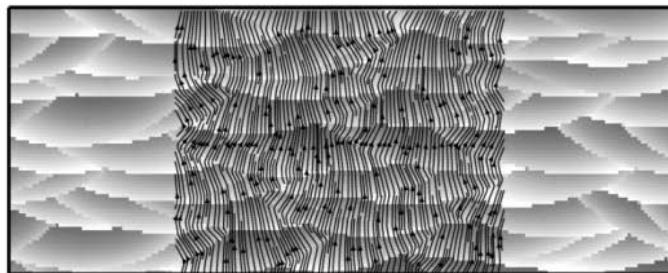
$$P = 594 \text{ W}, v = 2.2 \text{ m/s}, l = 150 \mu\text{m}$$

$$P = 627 \text{ W}, v = 8.8 \text{ m/s}, l = 37.5 \mu\text{m}$$

In718

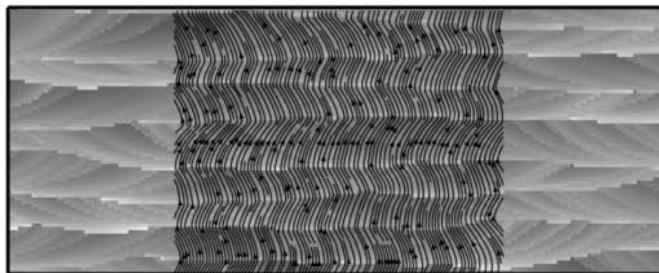


Classical CET theory fails!

columnar ∇T 

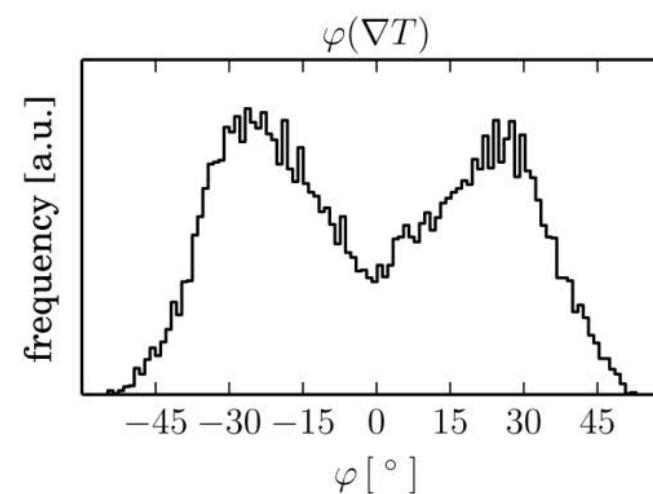
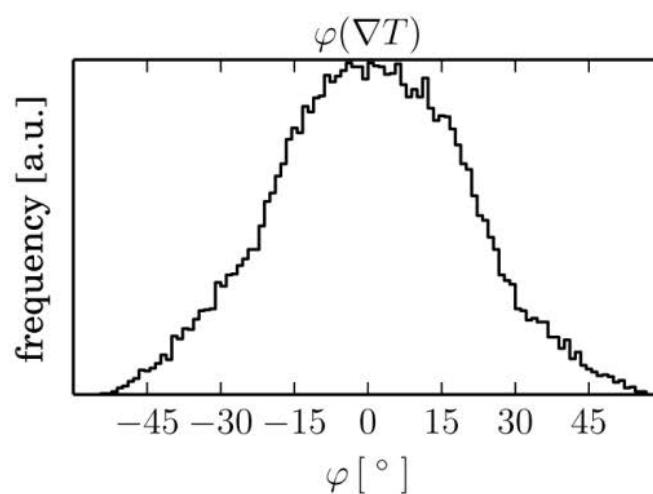
(a)

0 K/ μm 0.4 K/ μm

polycrystalline ∇T 

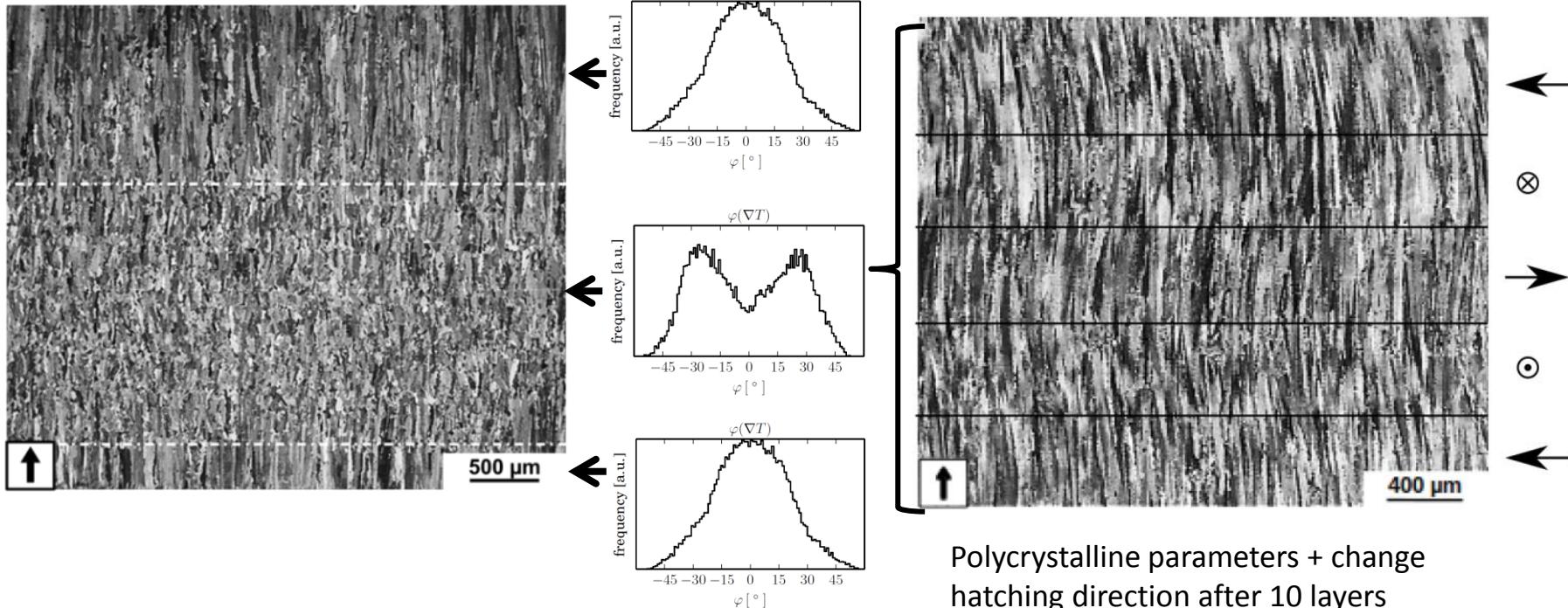
(b)

100 μm



Direction
changes
provoke
nucleation

In718

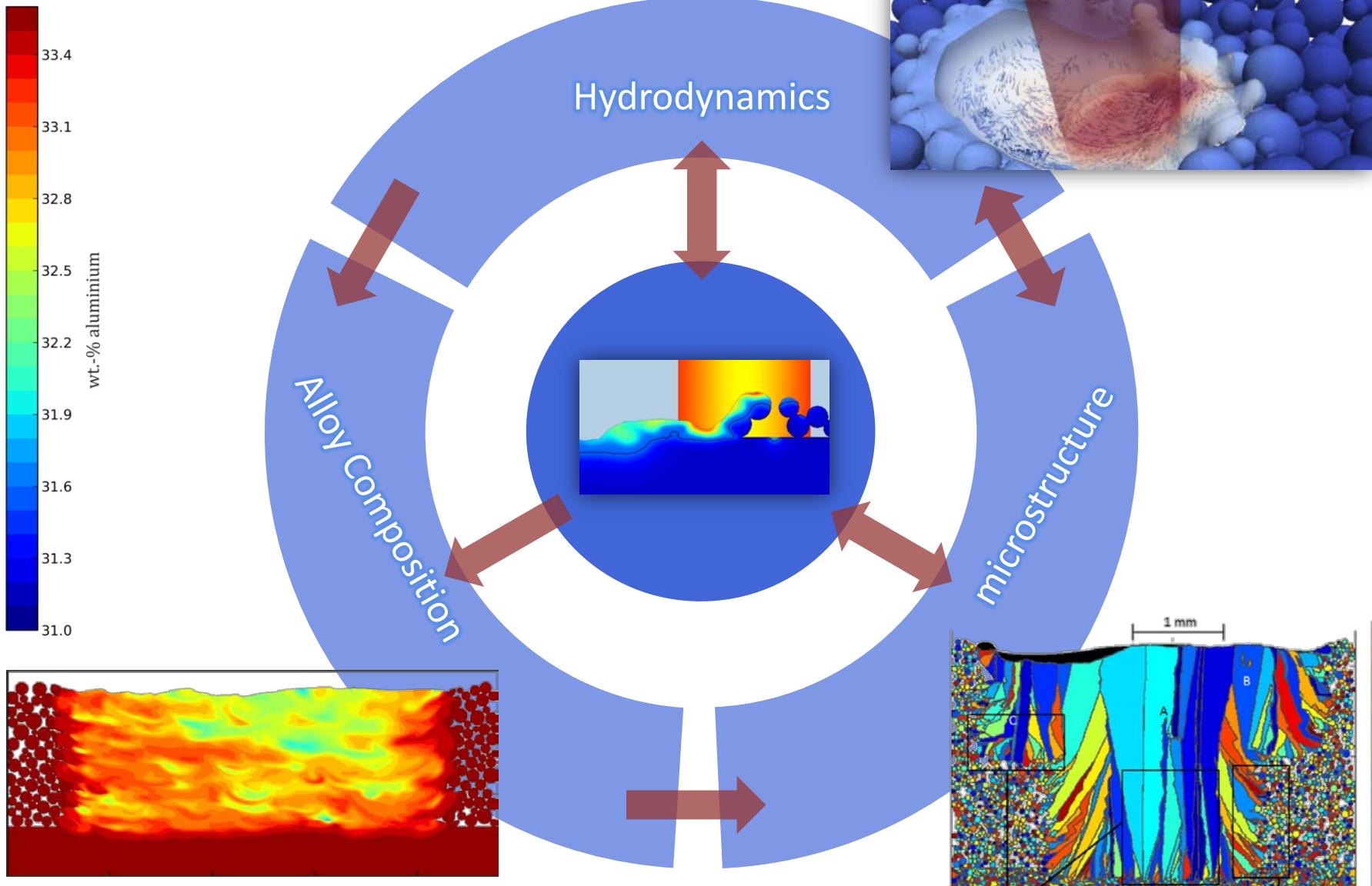


Microstructure not only determined by

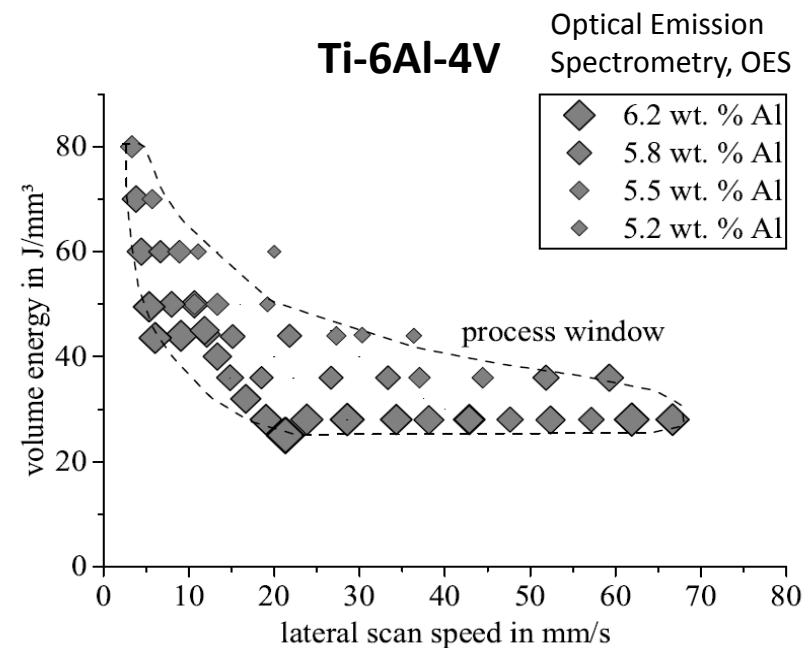
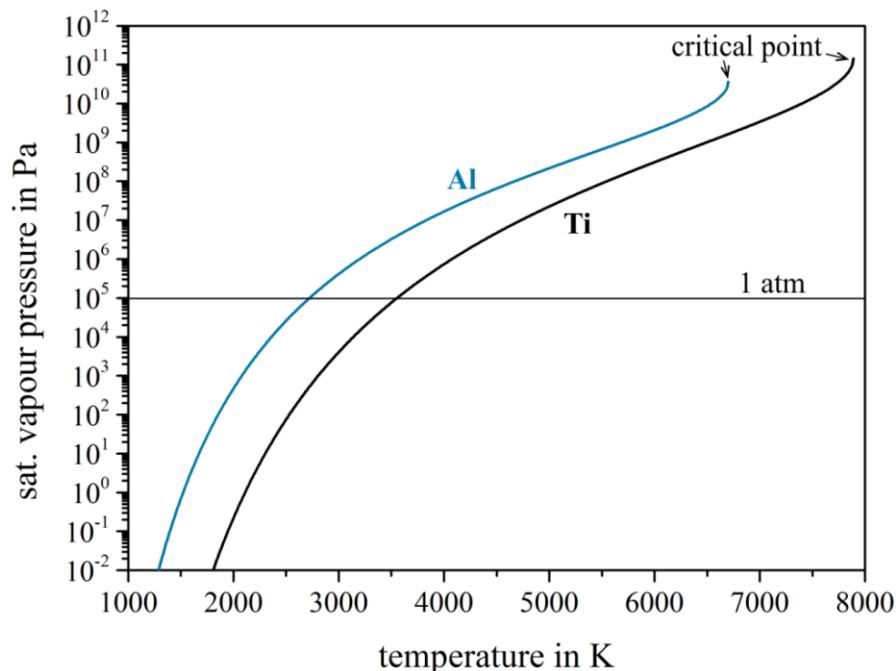
- solidification velocity
- temperature gradient and
- alloy composition

but also by the processing strategy.

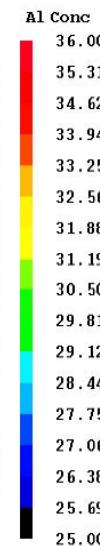
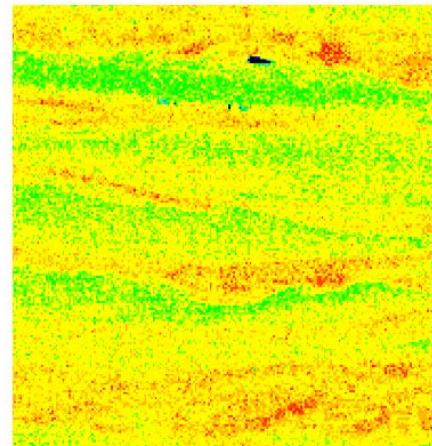
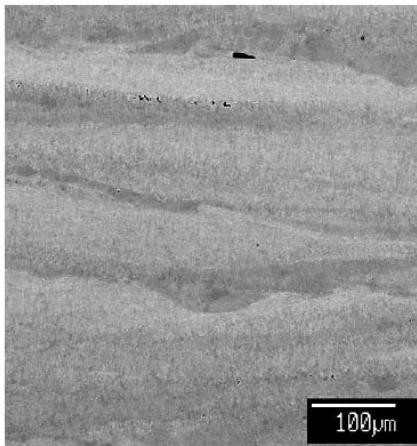
Processing strategy: Local influence
Changing the alloy: Global influence



Volatile elements such as Al or Zn

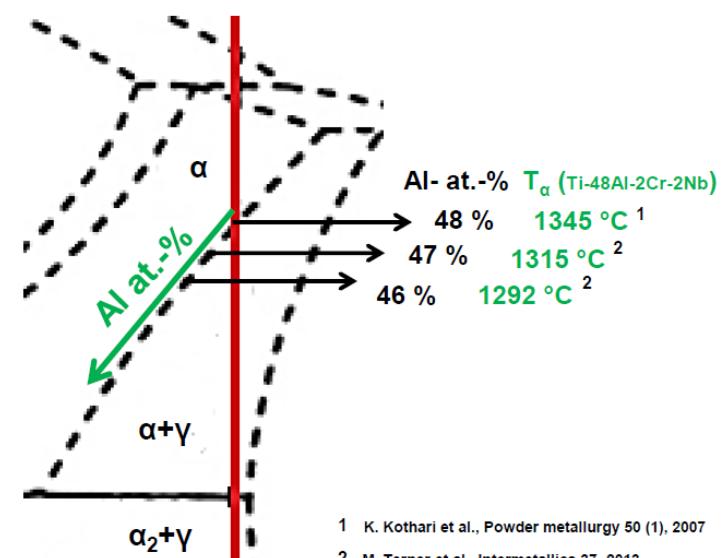
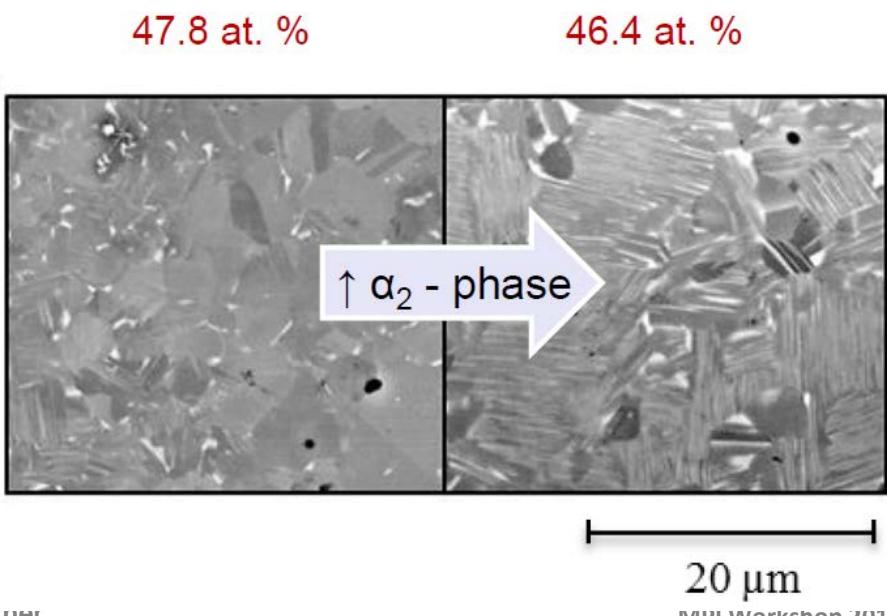


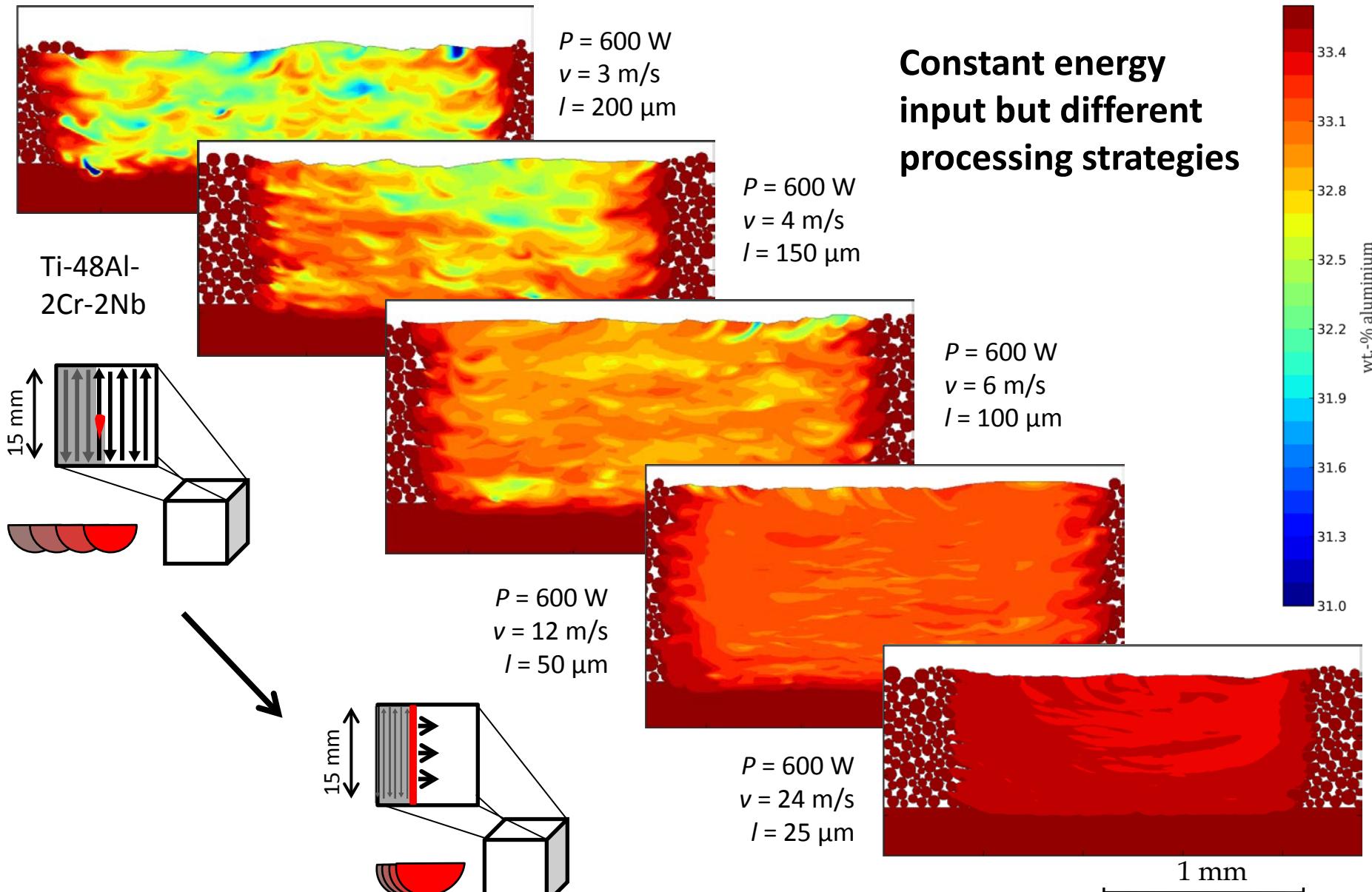
Composition depends on the processing strategy!

Ti-48Al-2Cr-2Nb

Global reduction of Al +
strong local variations

- Local variation of the phase composition
- Local variation of transus temperatures

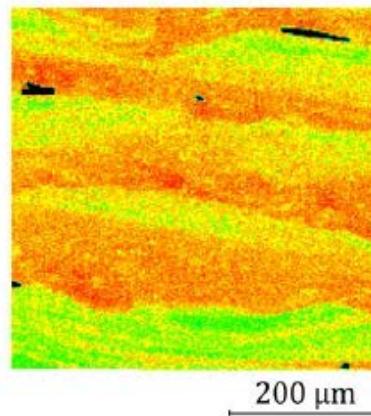




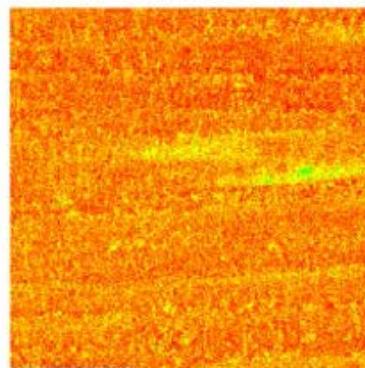
Ti-48Al-2Cr-2Nb

Experiment

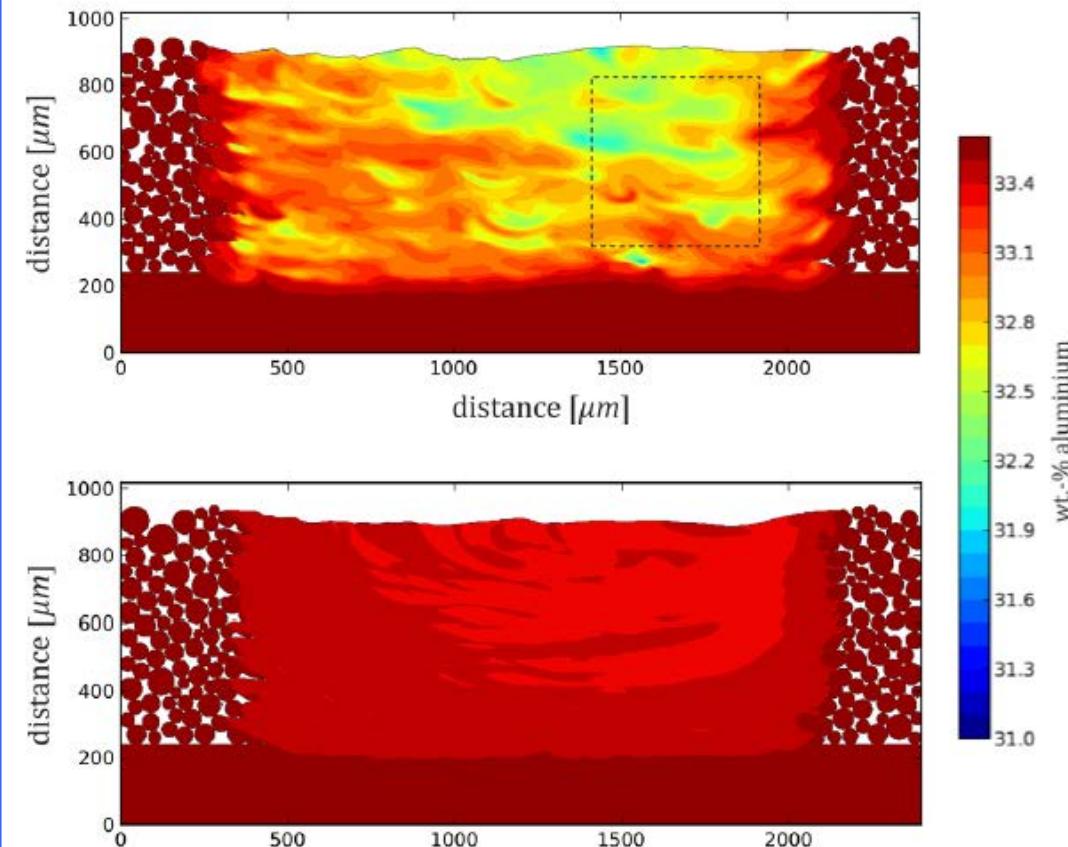
$P = 600 \text{ W}$
 $v = 4 \text{ m/s}$
 $l = 150 \mu\text{m}$



$P = 600 \text{ W}$
 $v = 24 \text{ m/s}$
 $l = 25 \mu\text{m}$

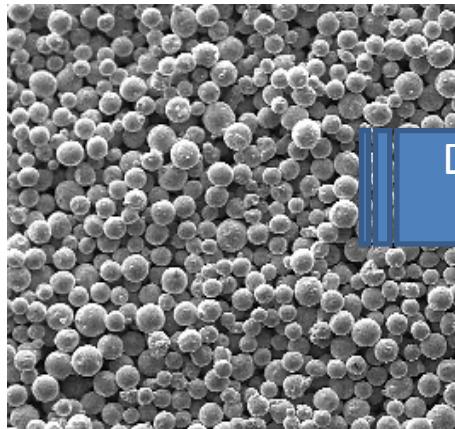


Simulation



[Klassen et al. Conference iCat (2014)]

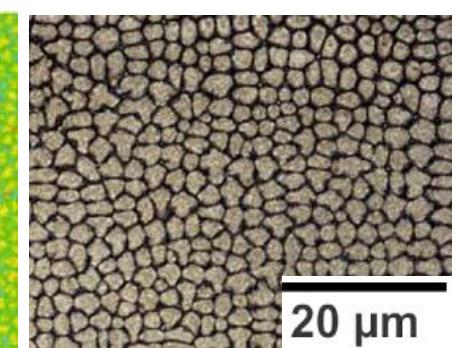
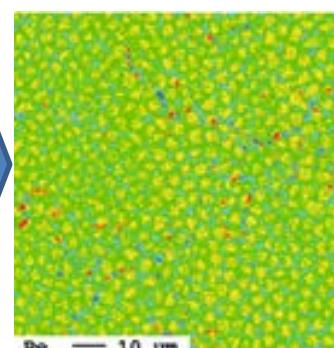
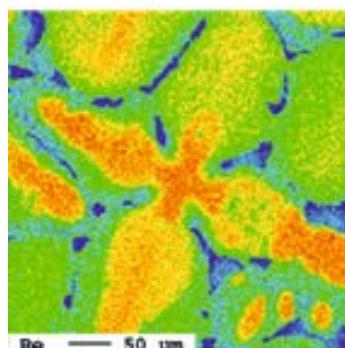
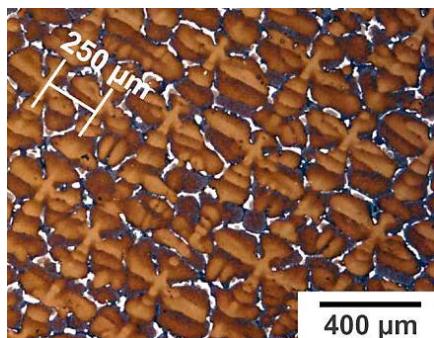
High homogeneity $\leftarrow \rightarrow$ new alloys



Design freedom, complexity, short lead time, etc.



Conventional Investment Casting

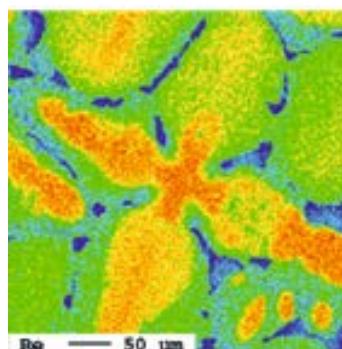
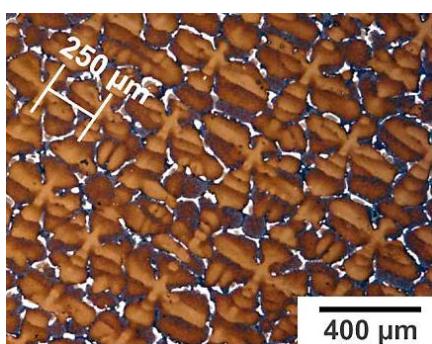


Additive Manufacturing: Rapid solidification

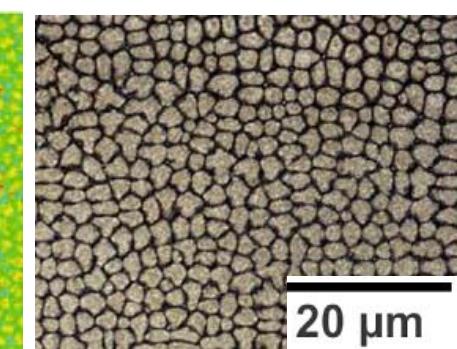
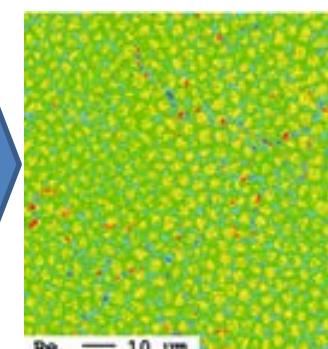


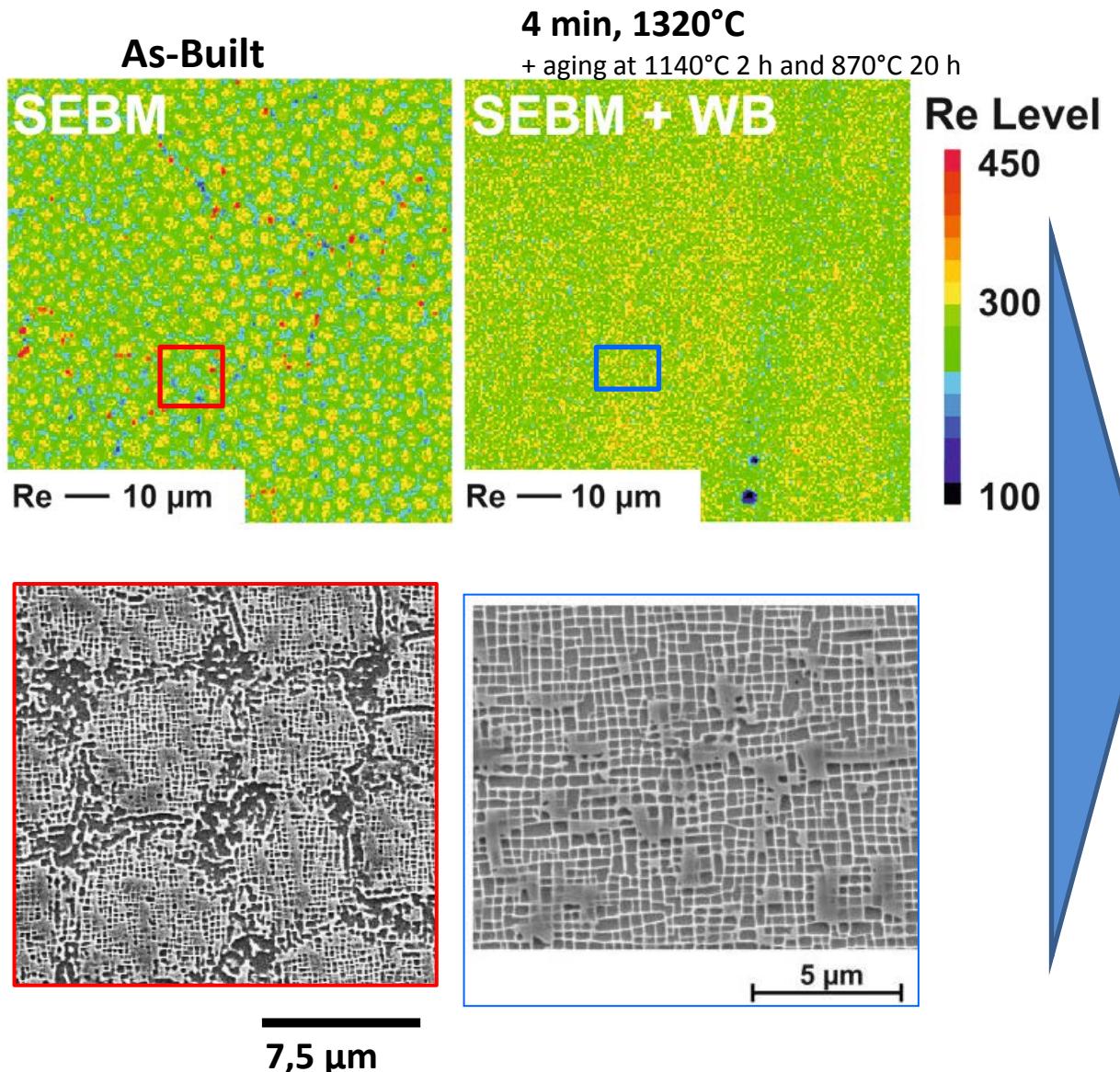
- Technological advantages: Easier and faster heat treatment
- Better material properties expected
- Metallurgical limitations vanish → new alloys possible

Conventional Investment Casting



Rapid solidification

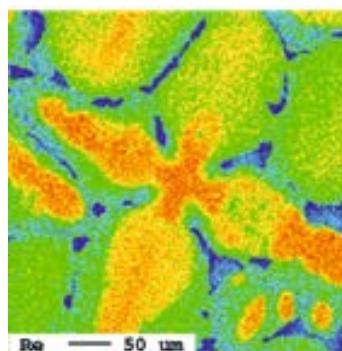
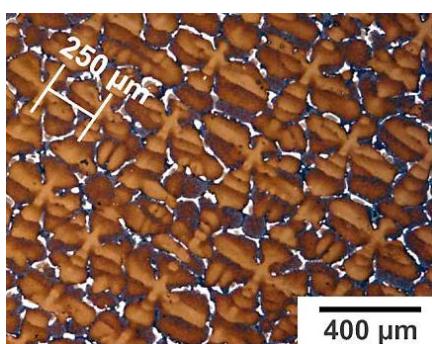




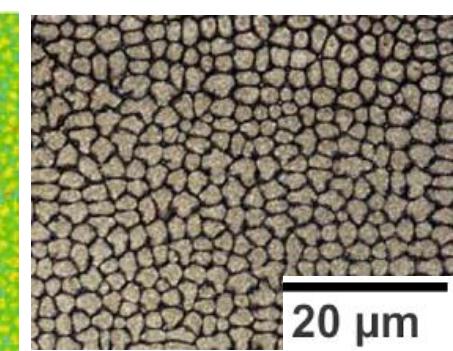
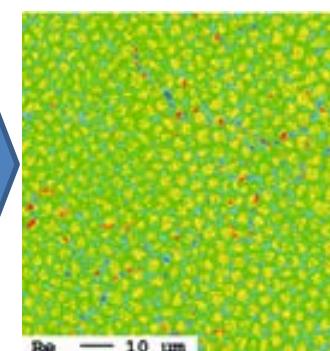


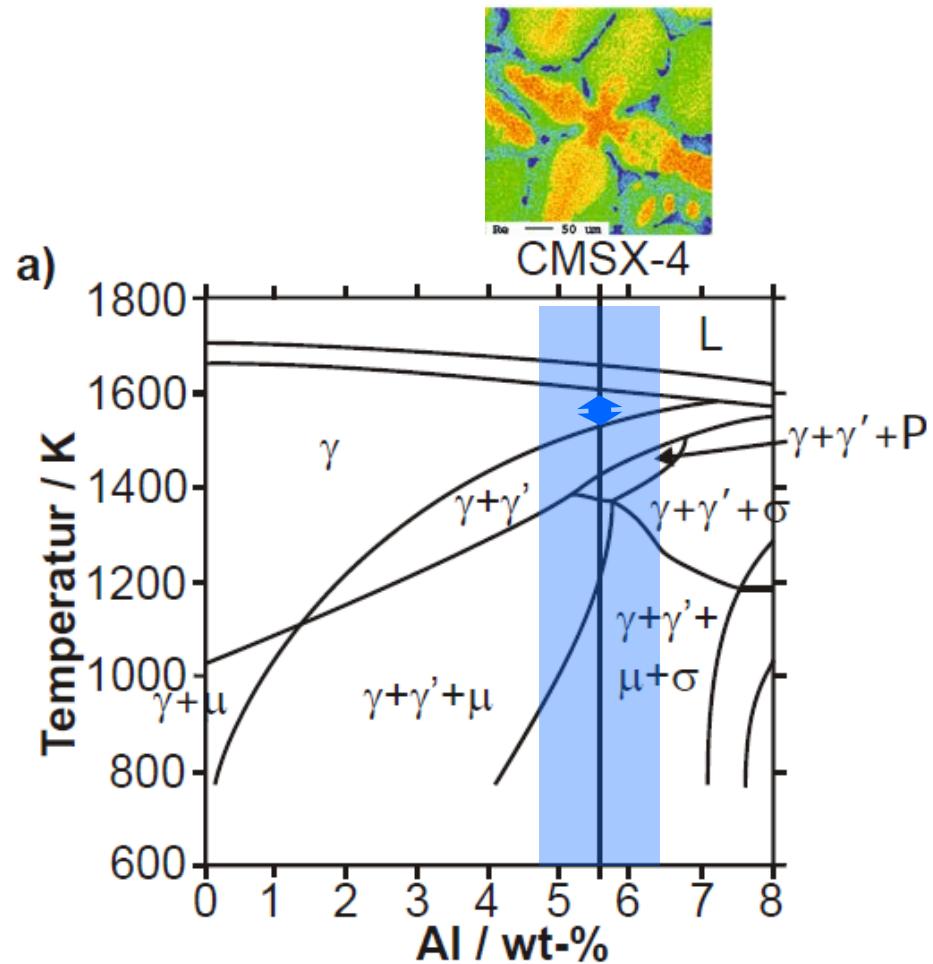
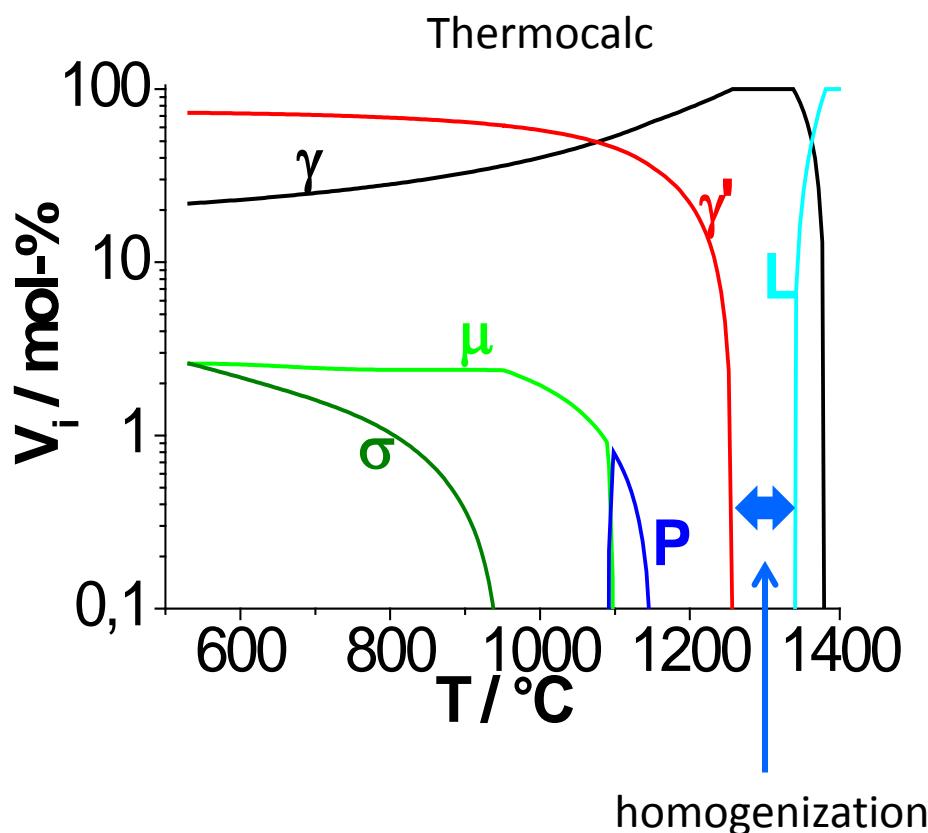
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Conventional Investment Casting



Rapid solidification

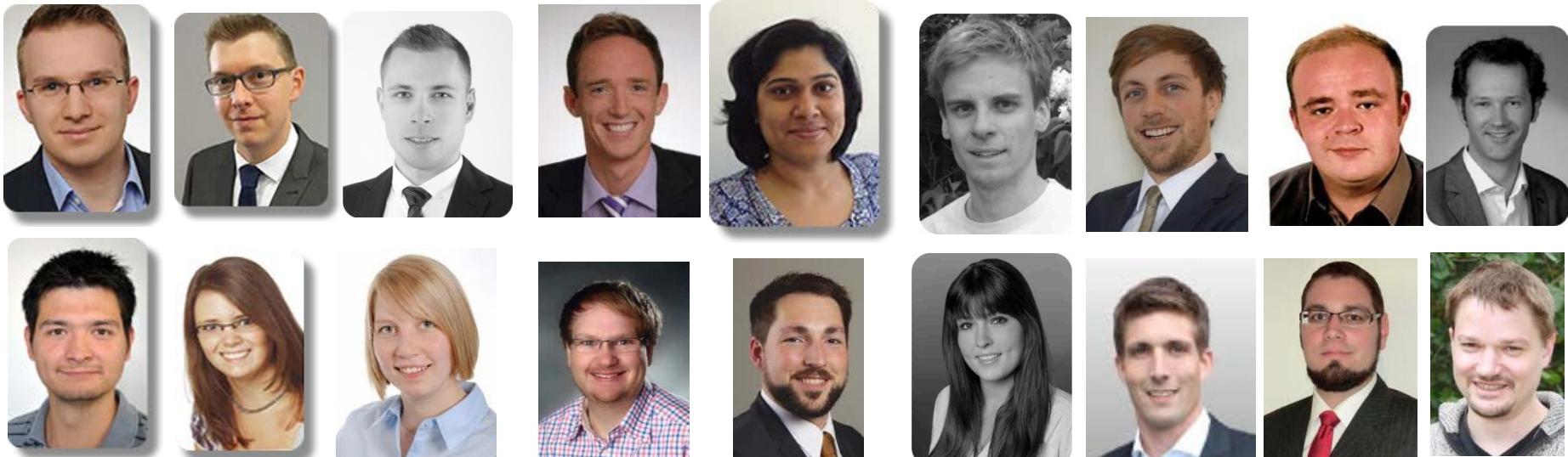




Local variation of the composition \rightarrow Variation of $T_m \rightarrow$ Danger of local melting!

- High supersaturation due to $T_{\max} \gg T_m$ und dT/dt
- Processing strategy $\leftarrow \rightarrow$ Grain structure
- Selective evaporation can be prevented by an adapted strategy \rightarrow volatile elements
- Extreme homogeneity overcomes limitations of classical melt metallurgy

**Alloy development and process development
have to be strongly coupled!**



Thank you!



aft, Infrastruktur, Verkehr und Technologie



Bayerisches Staatsministerium für
Wissenschaft, Forschung und Kunst

