

High Entropy Shape Memory Alloys (HESMA)

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Alloy Compositions, Processing and Microstructures

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LWW

Lehrstuhl Werkstoffwissenschaft

materials science and engineering

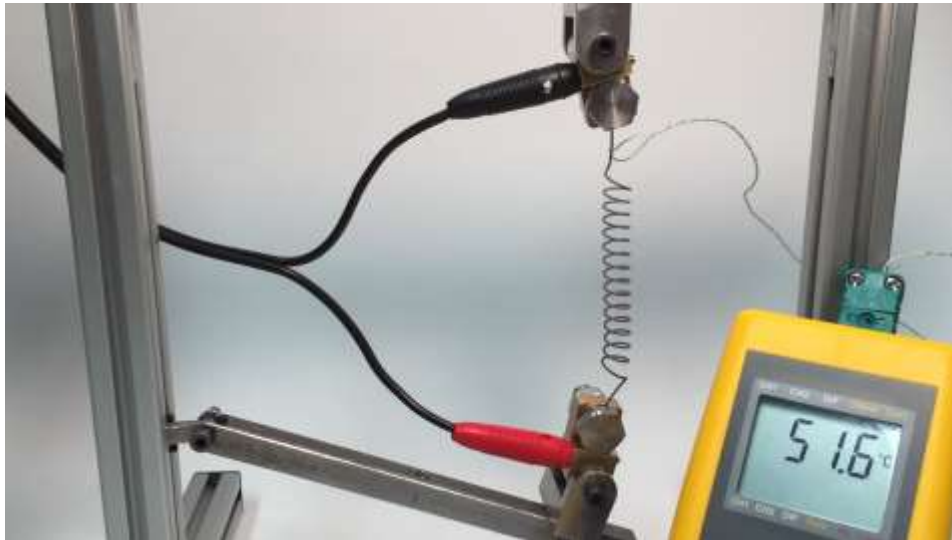


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Outline

- Shape memory alloys & martensitic transformation
- High entropy shape memory alloys
- Project and work programme
- Interactions in SPP

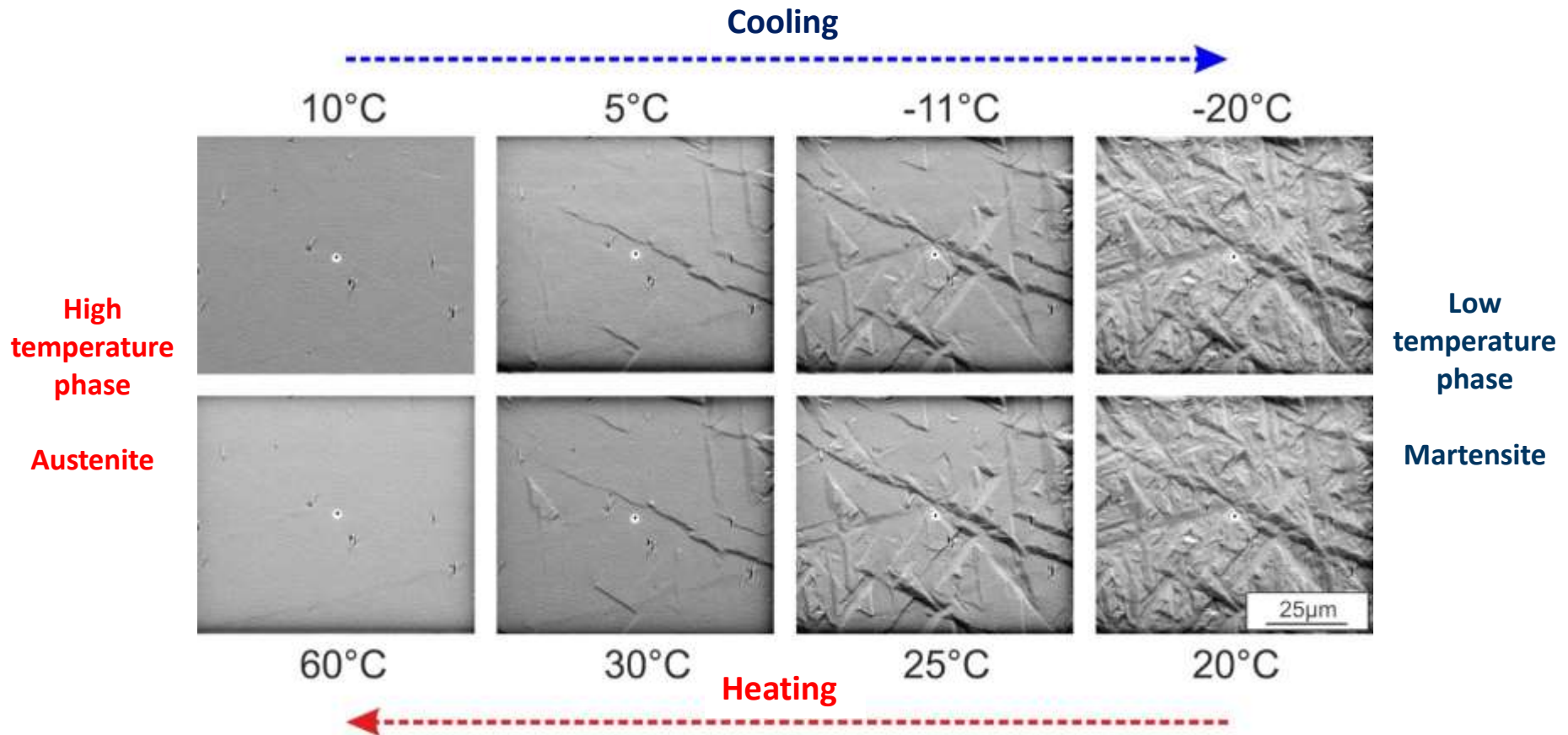
Shape memory alloys (SMAs)



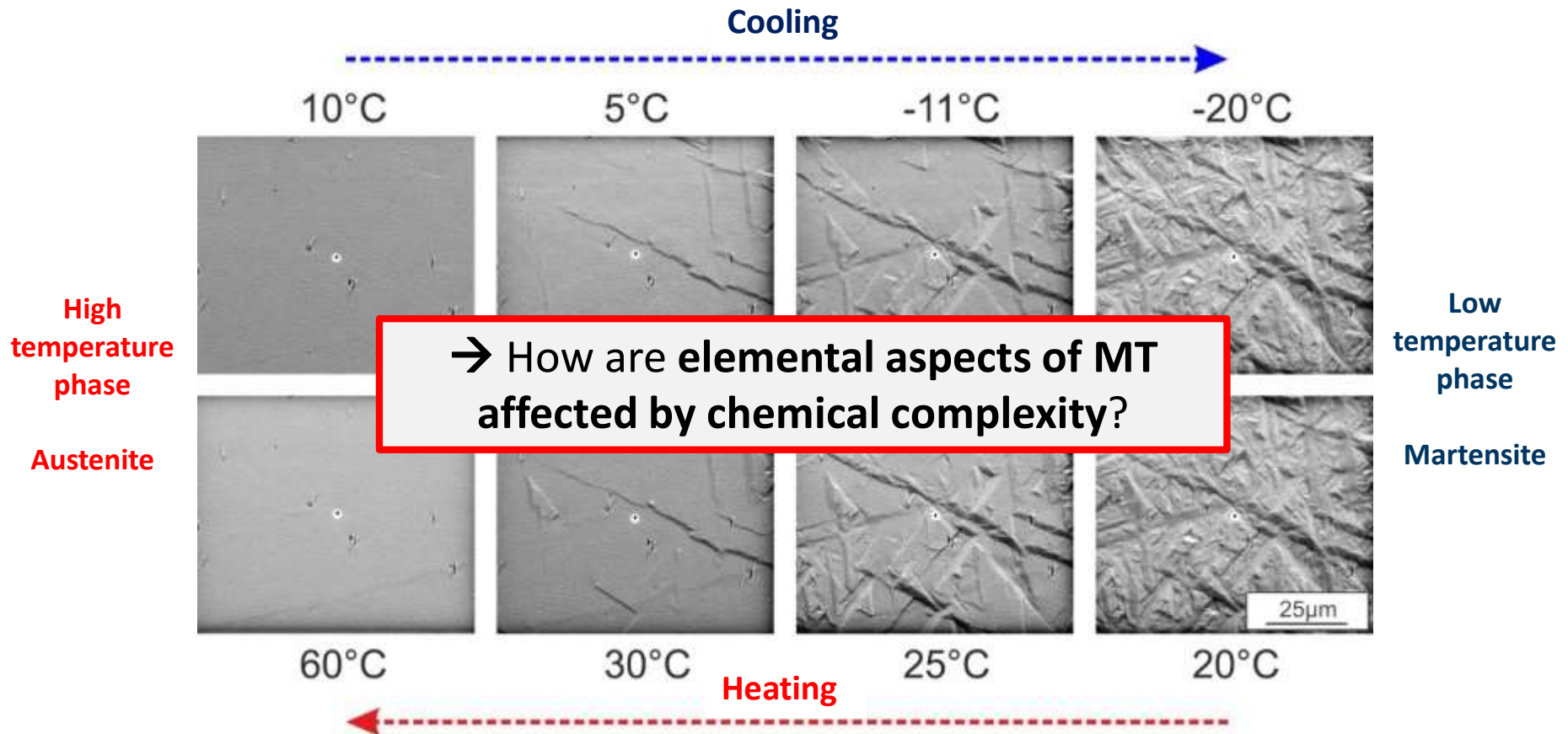
SMA spring actuator

- Shape recovery
- Two types of SM effects
 - Thermal memory
 - Mechanical memory
- Effects rely on reversible martensitic transformation (MT)
- Effects are governed by phase transformation temperatures (PTT)

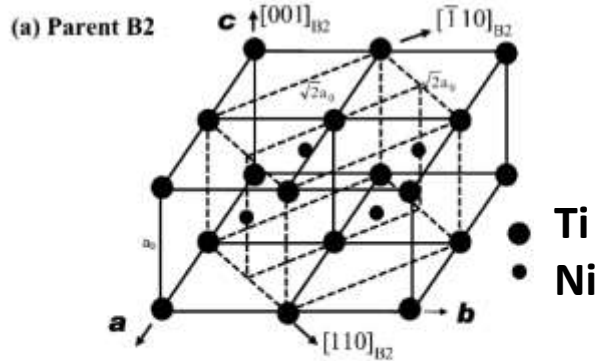
Martensitic transformation



Martensitic transformation



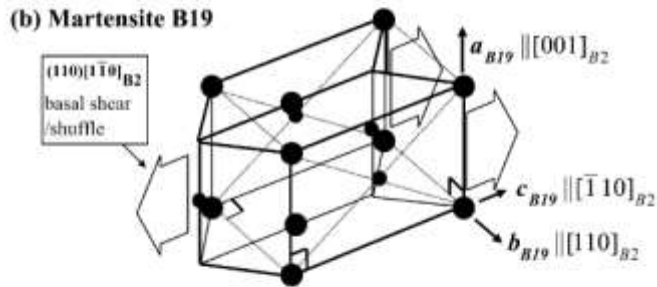
Martensitic transformation in Ni-Ti



B2

(β , austenite, ordered BCC - CsCl)

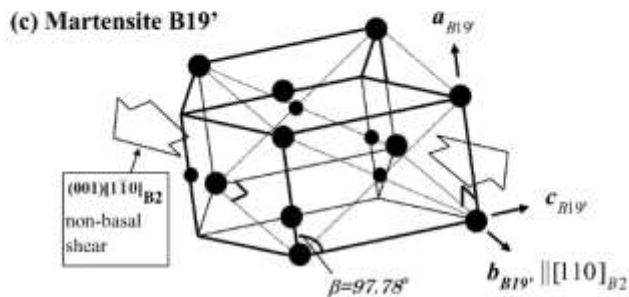
basal shear



B19

(α^+ / α^- , martensite, orthorhombic)

non basal shear



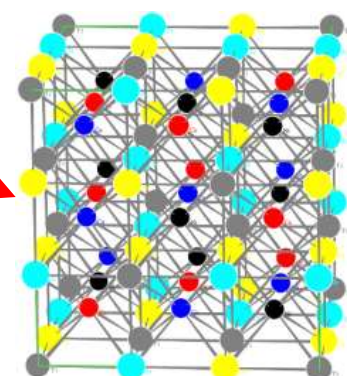
B19'

(α'^+ / α'^- martensite, monoclinic)

Transformation from B2 to B19'
(Otsuka & Ren, Progr. Mater. Sci. 50, 2005)

High entropy shape memory alloys

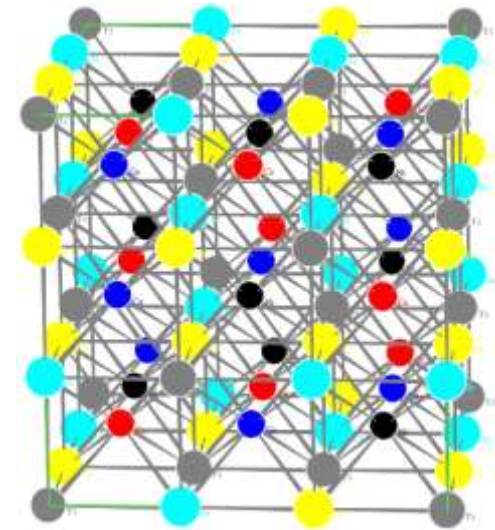
1 H Wasserstoff																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Bor	6 C Kohlenstoff	7 N Stickstoff	8 O Sauerstoff	9 F Fluor	10 Ne Neon
11 Na Natrium	12 Mg Magnesium											13 Al Aluminium	14 Si Silizium	15 P Phosphor	16 S Schwefel	17 Cl Chlor	18 Ar Argon
19 K Kalium	20 Ca Calcium	21 Sc Scandium	22 Ti Titan	23 V Vanadium	24 Cr Chrom	25 Mn Mangan	26 Fe Eisen	27 Co Cobalt	28 Ni Nickel	29 Cu Kupfer	30 Zn Zink	31 Ga Gallium	32 Ge Germanium	33 As Arsen	34 Se Selen	35 Br Brom	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirkon	41 Nb Niob	42 Mo Molybdän	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rheinium	46 Pd Palladium	47 Ag Silber	48 Cd Cadmium	49 In Indium	50 Sn Zinn	51 Sb Antimon	52 Te Tellur	53 I Jod	54 Xe Xenon
55 Cs Cäsium	56 Ba Baryum	57 La Lanthan	72 Hf Hafnium	73 Ta Tantal	74 W Wolfram	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platin	79 Au Gold	80 Hg Quecksilber	81 Tl Thallium	82 Pb Blei	83 Bi Bismut	84 Po Polonium	85 At Astat	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac Actinoid	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	117 Uus Ununseptium	118 Uuo Ununoctium	



VEC ~ 7 → HEA intermetallics with B2 type

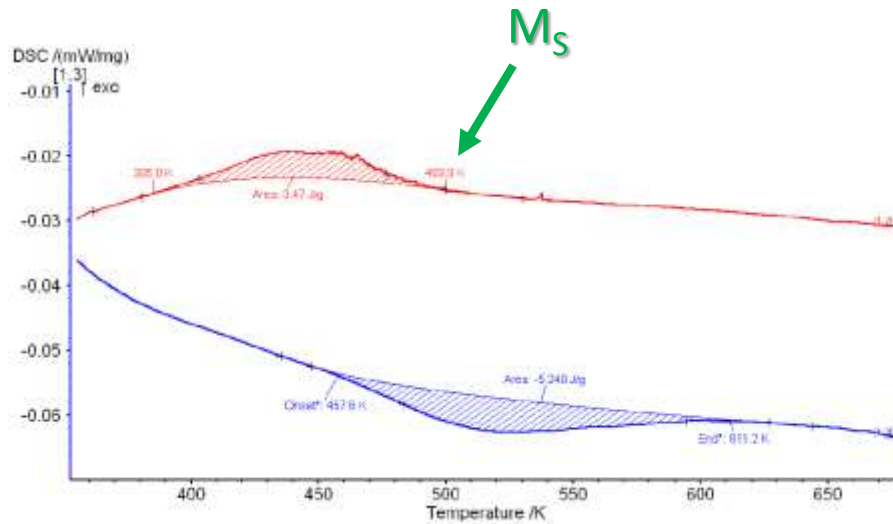
Crystal structure of HESMAs

- XRD and DFT by Firstov et al. (2015)
- $\text{Ti}_9\text{Zr}_9\text{Hf}_9\text{Ni}_9\text{Cu}_9\text{Co}_9$ -Unit cell
 - Ti-sublattice-sites occupied by Ti, Hf, Zr
 - Ni-sublattice-sites occupied by Ni, Cu, Co
- Unlike to B2, slightly triclinic
 - Lattice distortion
- Higher configurational entropy than in binary NiTi
 - Ordered solid solution HEA



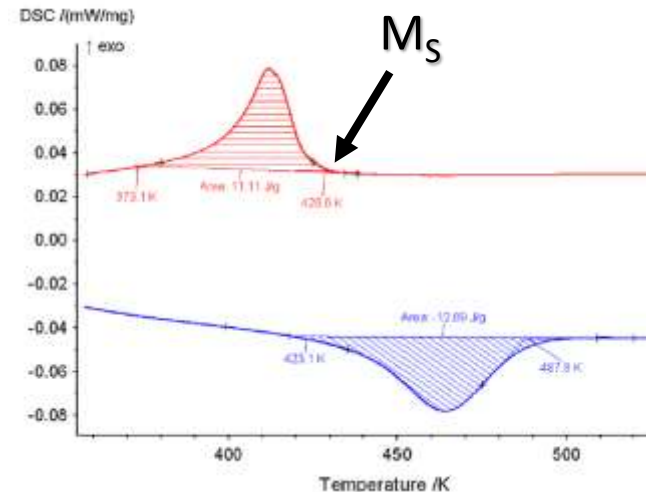
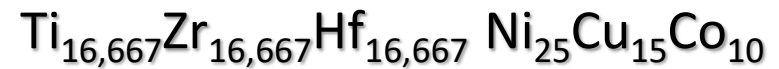
B2-related triclinic P1 phase of HESMA
(Firstov et al., Matec. Web Conf. 33, 2015)

Phase transformation behavior of HESMAs



(Firstov et al., Matec. Web Conf. 33, 2015)

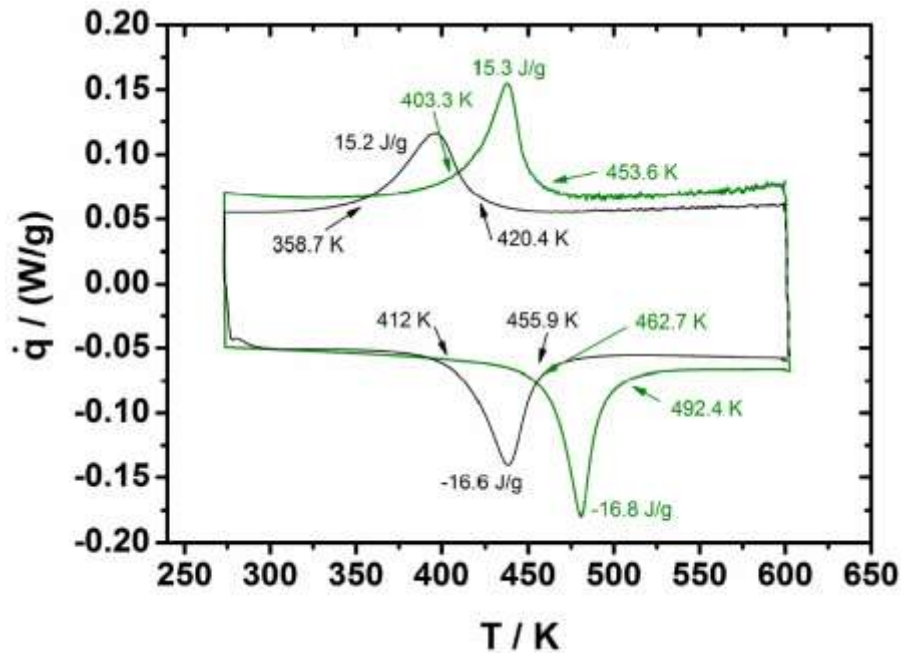
$M_S = 500 \text{ K} / 217 \text{ }^\circ\text{C}$



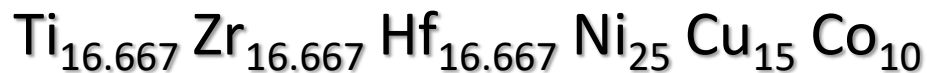
(Firstov et al., Sha. Mem. and Superelas., 2015)

$M_S = 430 \text{ K} / 157 \text{ }^\circ\text{C}$

HESMAs made in Bochum

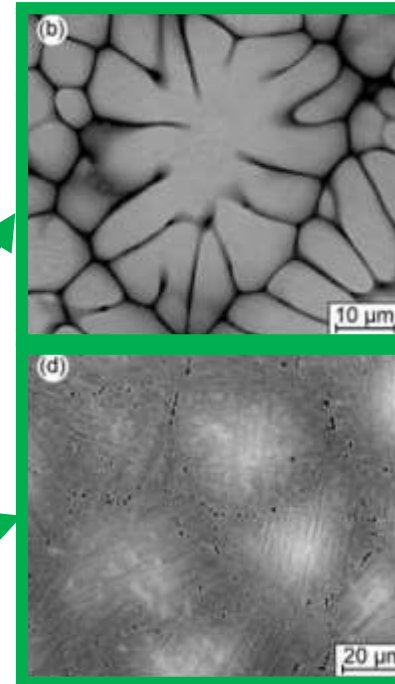
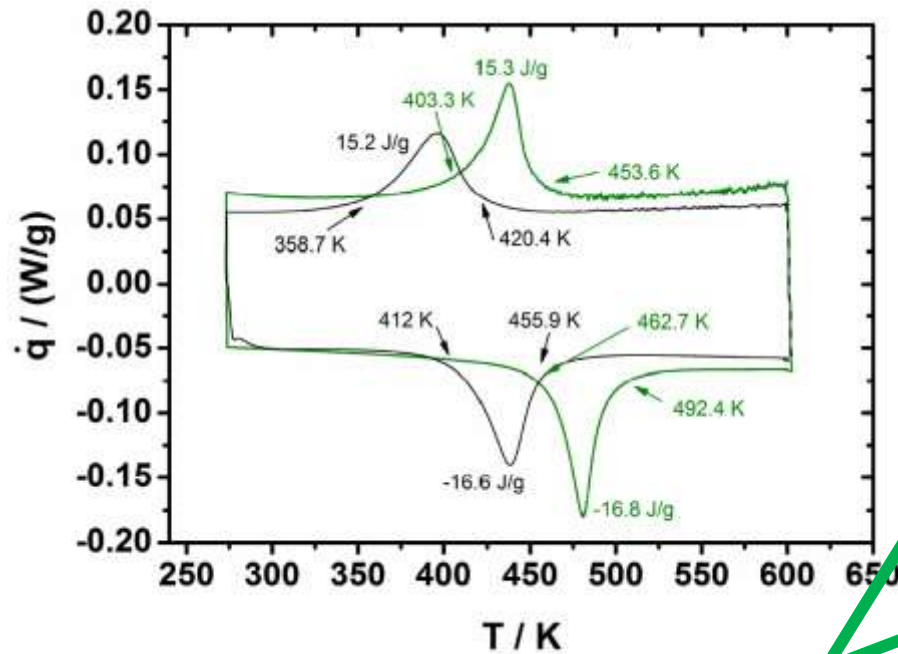


→ $M_S = 454 \text{ K} / 181 \text{ °C}$



→ $M_S = 403 \text{ K} / 130 \text{ °C}$

HESMAs made in Bochum



As-cast

900 °C / 72 h

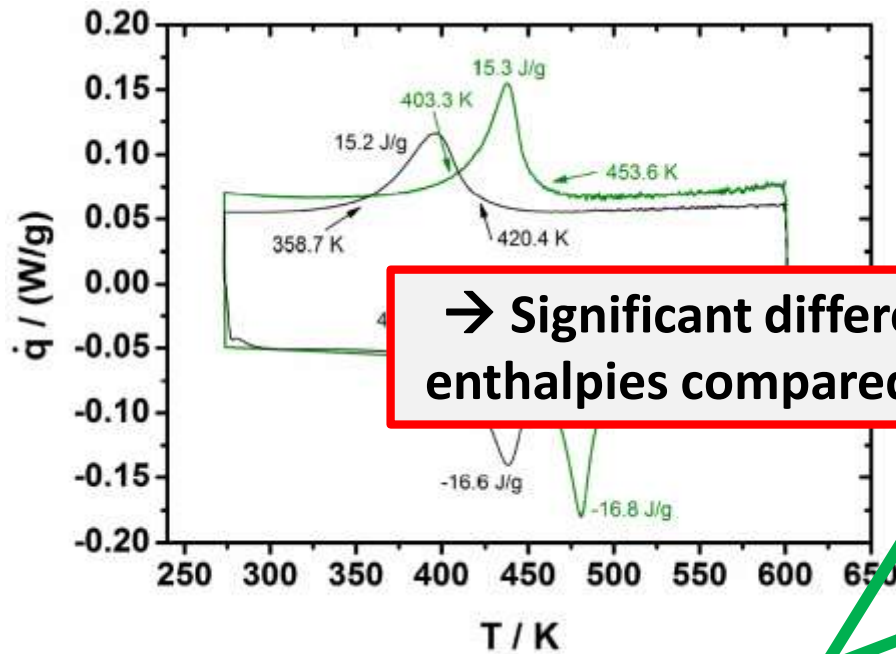


→ $M_S = 454 \text{ K} / 181 \text{ °C}$



→ $M_S = 403 \text{ K} / 130 \text{ °C}$

HESMAs made in Bochum



→ Significant differences in PTTs and enthalpies compared to Firstov results

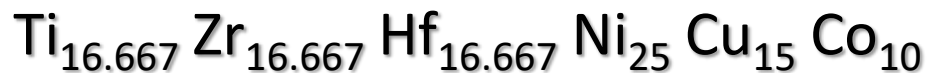


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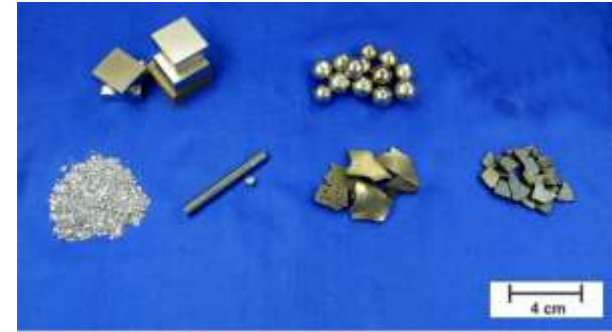
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Project and work programme

Microstructure-Functional Behavior-Relationships in High Entropy Shape Memory Alloys



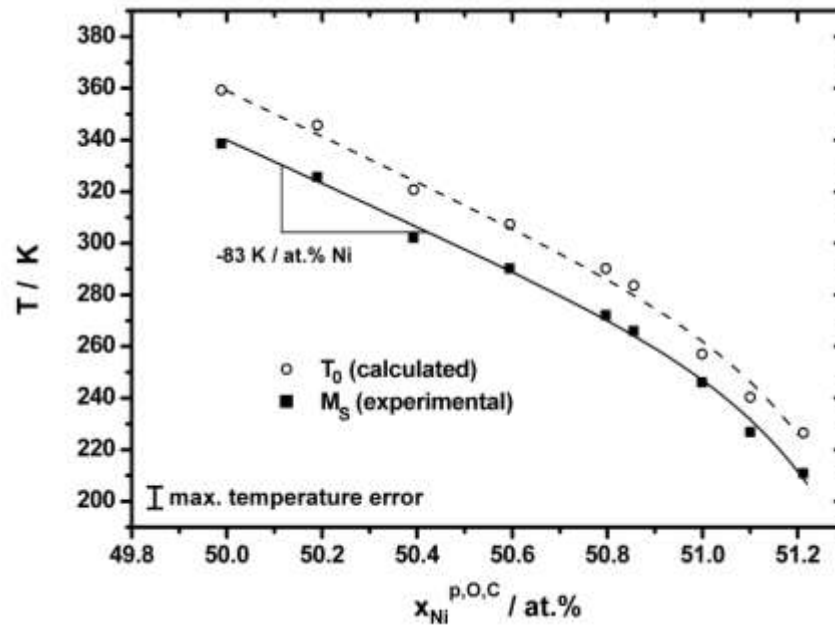
- Ingot metallurgy and compositional screening
- Characterization of martensitic transformation
- Phase stability and atomic mobilities
- Thermo-mechanical processing and heat treatment
- Basic mechanical properties
- Thermo-mechanical fatigue testing to assess functional fatigue resistance
- Identification of functional degradation mechanisms
- Structural fatigue



Processing of HESMAs

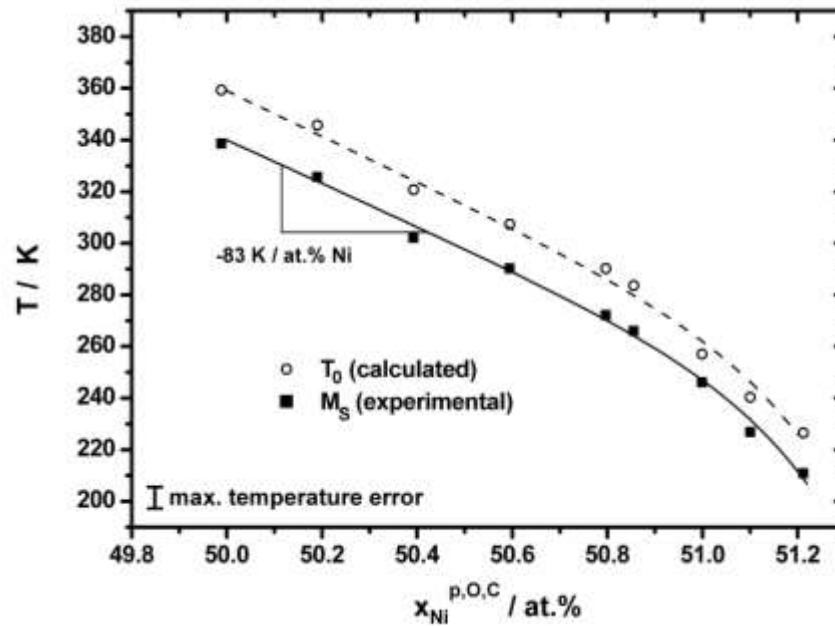


Alloy composition and PTTs



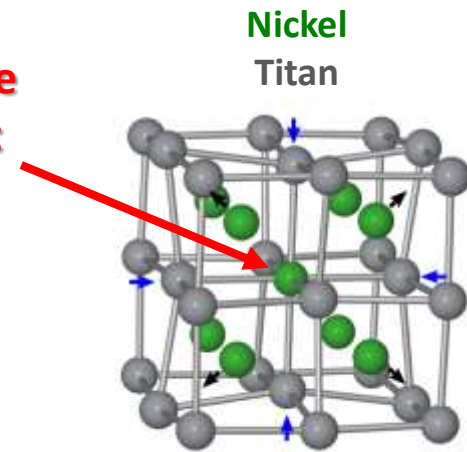
(Frenzel et al., Acta Mat. 58, 2010)

Alloy composition and PTTs



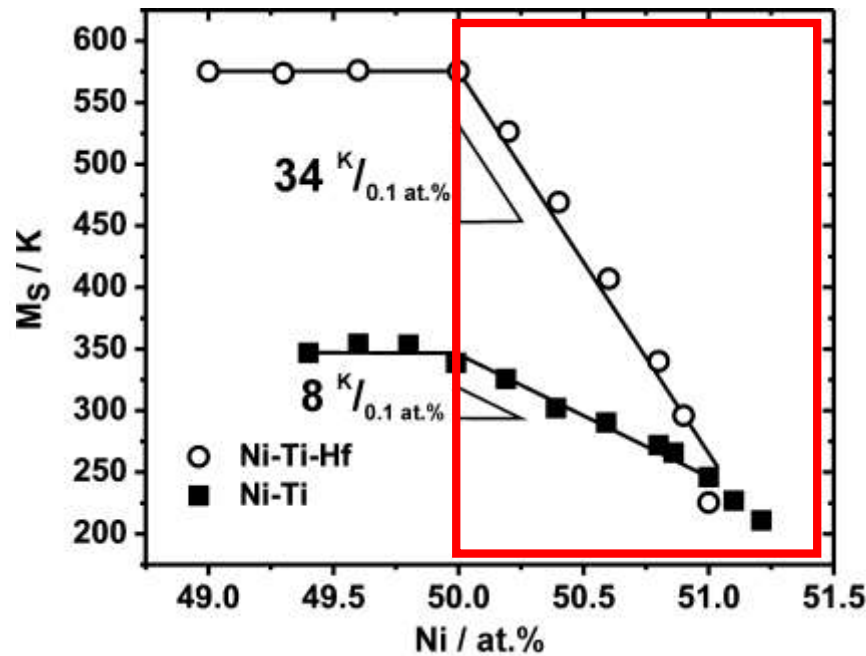
(Frenzel et al., Acta Mat. 58, 2010)

Anti-site
defect



(Frenzel et al., Acta Mat. 90, 2015)

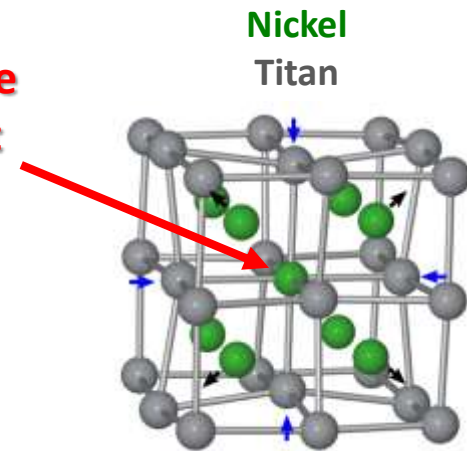
Alloy composition and PTTs



(Frenzel et al., Acta Mat. 58, 2010)

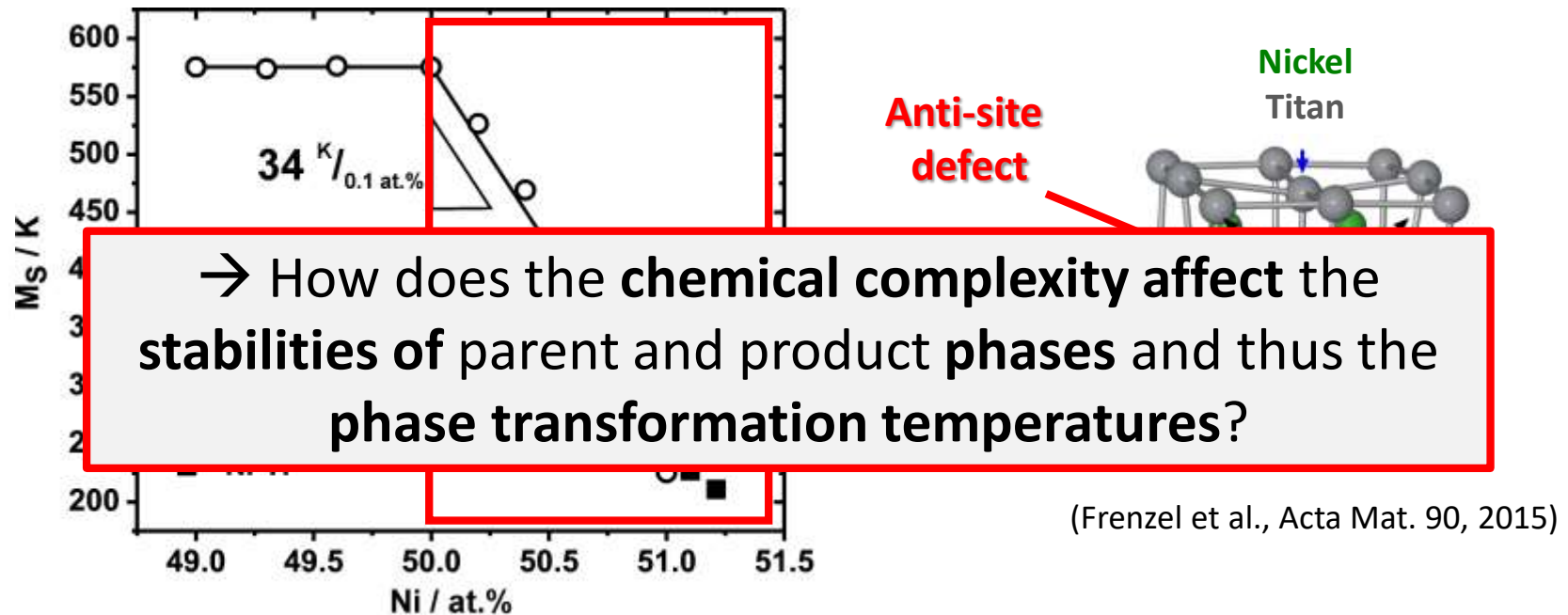
(preliminary work)

Anti-site
defect



(Frenzel et al., Acta Mat. 90, 2015)

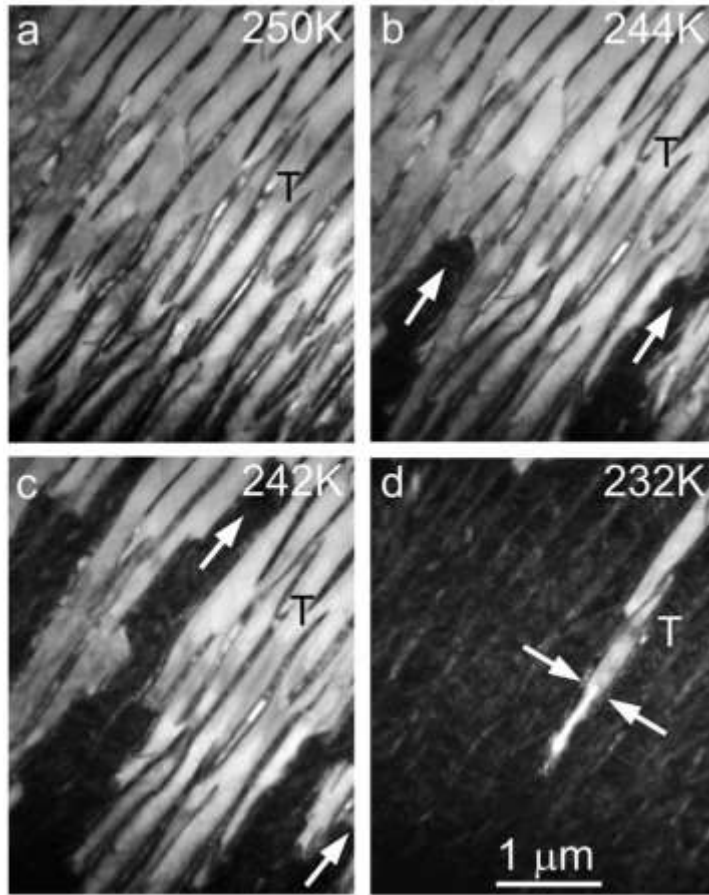
Alloy composition and PTTs



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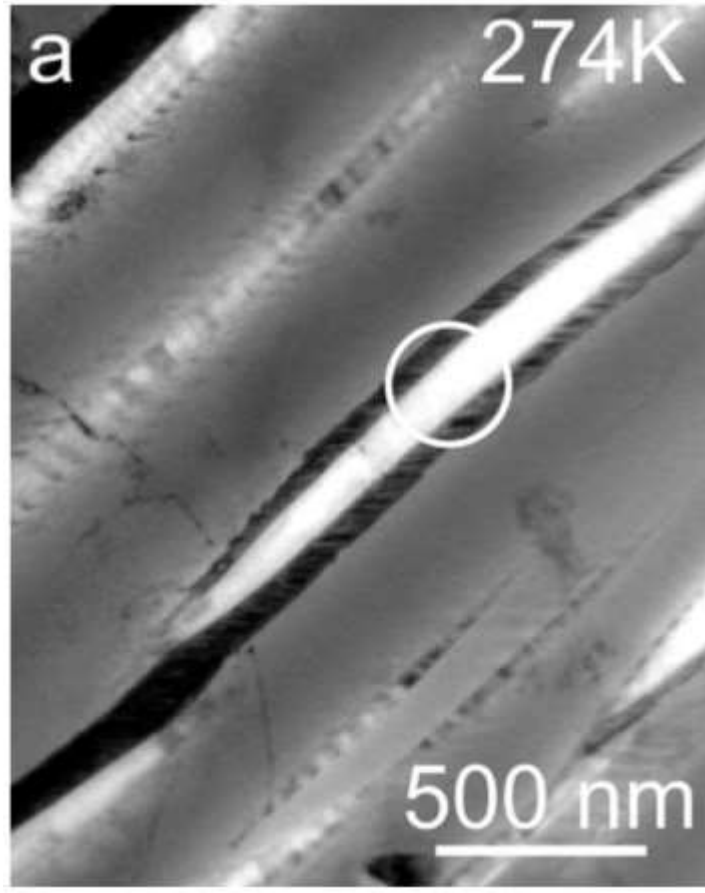
Aging and phase stability



- Elementary MT processes depend strongly on microstructure and phase stability
- Aging \rightarrow Ni_4Ti_3 precipitates
- Multi-step MTs ($\text{B2} \rightarrow \text{R} \rightarrow \text{B19}'$)

(Michutta et al., Acta Mat. 33, 2015)

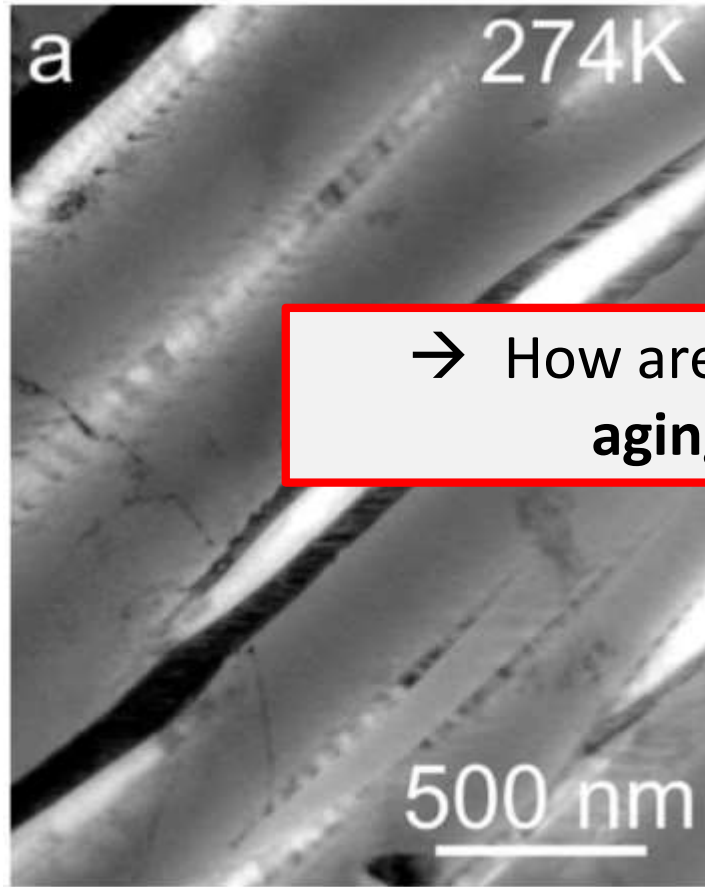
Aging and phase stability



(Michutta et al., Acta Mat. 33, 2015)

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- Aging \rightarrow Ni_4Ti_3 precipitates
- Multi-step MTs ($\text{B2} \rightarrow \text{R} \rightarrow \text{B19}'$)
- **B19' nucleation** not only determined by **large-scale** (Δc) but also **small-scale heterogeneities**

Aging and phase stability



- Elementary MT processes depend strongly on microstructure and phase stability

→ How are HESMAs affected by aging treatments?

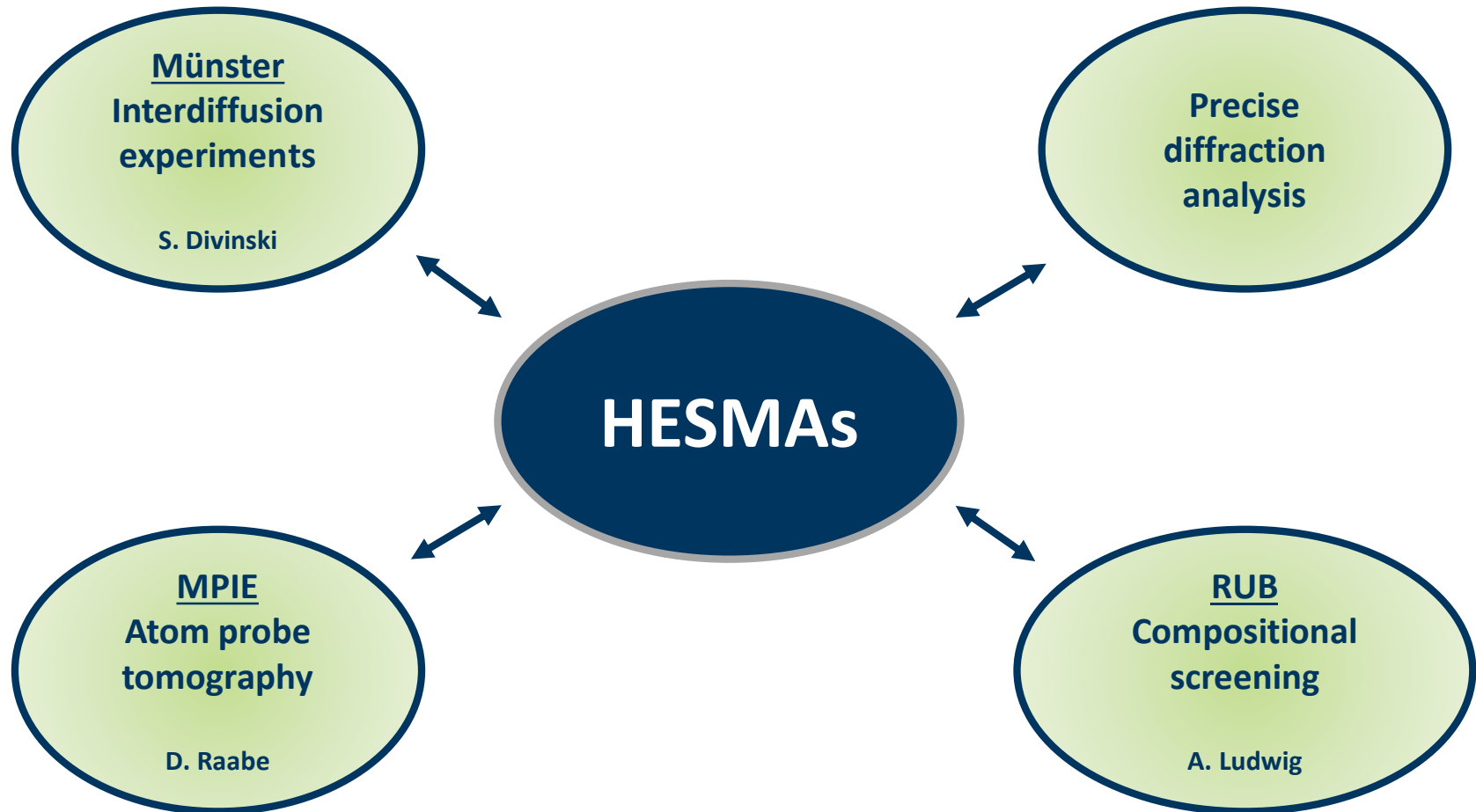
precipitates

→ R → B19'

- **B19' nucleation** not only determined by **large-scale** (Δc) but also **small-scale heterogeneities**

(Michutta et al., Acta Mat. 33, 2015)

Interactions in SPP



Thank you for your attention!